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Generation Expansion of a Hydro Producer by Constructing Pumped-Storage Plant

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Abstract— **This paper addresses the generation expansion of a price-taker hydro generating company by means of pumped-storage plant construction. This company comprises several cascaded hydro plants along a river basin. By assuming the existence of a suitable zone as a natural reservoir, the hydro producer would like to evaluate the economic justification of pumped-storage plant construction using the mentioned natural zone as upper reservoir and one of his hydro reservoirs as lower reservoir. It is essential to have an appropriate strategy to calculate the profit amount. Hence, a comprehensive approach to self-schedule hydro producer before and after of pumped-storage construction is developed. Then, the economic justification of pumped-storage plant construction can be determined using Internal Rate of Return (IRR) index during its expected life time. The self-scheduling problem of hydro producer is therefore formulated and solved as a mixed integer non-linear programming (MINLP) problem. Numerical results for a case study are discussed.**

Index Terms—**Hydro producer, Pumped-storage plant, Generation expansion, Self-scheduling, Energy market, Spinning reserve market, Regulation market**

NOMENCLATURE

Functions:

$\phi_{h,i}(x_i, u_i, t)$ Power generation function of *i-th* hydro plant

$\phi_{p,s}(x_p, u_p, t)$ Power generation function of pumped-storage plant in its selling (discharging) mode

$\phi_{p,p}(x_p, w_i, t)$ Power consumption function of pumped-storage plant in its purchasing (charging) mode

Variables:

$\lambda_e(t)$ Market-clearing price of energy market on hour *t* (\$/MWh)

$\lambda_s(t)$ Market-clearing price of spinning reserve market on hour *t* (\$/MWh)

$\lambda_r(t)$ Market-clearing price of regulation market on hour *t* (\$/MWh)

$\lambda_{spot}(t)$ Market-clearing price of spot market on hour *t* (\$/MWh)

$P_{he,i}(t)$ Amount of power participated by *i-th* hydro plant to sell in the energy market at hour *t* (MW)

$P_{hs,i}(t)$ Amount of power participated by *i-th* hydro plant in the spinning reserve market at hour *t* (MW)

$P_{hr,i}(t)$ Amount of power participated by *i-th* hydro plant in the regulation market at hour *t* (MW)

$P_{pe,s}(t)$ Amount of power participated by pumped-storage plant to sell in the energy market at hour *t* (MW)

$P_{pe,p}(t)$ Amount of power participated by pumped-storage plant to purchase in the energy market at hour *t* (MW)

$P_{ps,s}(t)$ Amount of power participated by pumped-storage plant in the spinning reserve market at hour *t*, when pumped-storage operates in its selling mode (MW)

$P_{ps,p}(t)$ Amount of power participated by pumped-storage plant in the spinning reserve market at hour *t*, when pumped-storage operates in its purchasing mode (MW)

$P_{pr}(t)$ Amount of power participated by pumped-storage plant in the regulation market at hour *t* (MW)

$P_{t,i}(t)$ Amount of power consumed by pumped-storage plant which is supplied by *i-th* hydro plant at hour *t* (MW)

$P_{hexp,i}(t)$ Amount of expected power to be generated by *i-th* hydro plant in energy and ancillary service markets on hour *t* (MW)

$P_{pexp.}(t)$ Amount of expected power to be generated by pumped-storage plant in energy and ancillary service markets on hour *t* (MW)

$SU_i(t)$ Start-up cost of *i-th* hydro plant on hour *t* (\$)

$x_i(t)$ Reservoir storage of *i-th* hydro plant on hour *t* (Hm^3)

$u_i(t)$ Water discharge of *i-th* hydro plant on hour *t* (Hm^3)

$x_p(t)$ Reservoir storage of pumped-storage plant on hour *t* (Hm^3)

$u_p(t)$ Water discharge of pumped-storage plant on hour *t* (Hm^3)

$v_i(t)$ Water spillage of *i-th* regulating hydro plant on

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	hour t (Hm^3)
$y_i(t)$	Independent inflow into reservoir of *i-th* hydro plant on hour t (Hm^3)
$z_i(t)$	Dependent inflow into reservoir of *i-th* hydro plant on hour t due to discharge and spillage of upstream plants (Hm^3)
$w_i(t)$	Water charge of pumped-storage plant supplied by *i-th* hydro plant on hour t (Hm^3)

Binary variable:

$d_i(t)$	Indicates whether the *i-th* hydro plant is on-line or not at hour t
$d_s(t)$	Indicates whether the pumped-storage plant is in its selling mode at hour t
$d_p(t)$	Indicates whether the pumped-storage plant is in its purchasing mode at hour t

Constants:

$P_{del.}$	The probability of calling plants to generate in the spinning reserve market
$P_{r,up}$	The probability of being in the regulation-up state in the regulation market
$P_{r,down}$	The probability of being in the regulation-down state in the regulation market
SU_i	Start-up cost of *i-th* hydro plant ($)
β	Adjusting constant of stored water for subsequent time interval
$\underline{X}_i, \overline{X}_i$	Bounds on reservoir storage of *i-th* hydro plant (Hm^3)
$\underline{U}_i, \overline{U}_i$	Bounds on water discharge of *i-th* hydro plant (Hm^3)
$\underline{X}_p, \overline{X}_p$	Bounds on reservoir storage of pumped-storage plant (Hm^3)
$\underline{U}_p, \overline{U}_p$	Bounds on water discharge of pumped-storage plant (Hm^3)
$\underline{V}_i, \overline{V}_i$	Bounds on water spillage of *i-th* hydro plant (Hm^3)
X_i^0	Amount of reservoir storage of *i-th* hydro plant in the beginning of concerned time interval (Hm^3)
X_i^{end}	Amount of reservoir storage of *i-th* hydro plant in the end of concerned time interval (Hm^3)
X_p^0	Amount of reservoir storage of pumped-storage plant in the beginning of concerned time interval (Hm^3)
X_p^{end}	Amount of reservoir storage of pumped-storage plant in the end of concerned time interval (Hm^3)
$\tau_{m,i}$	Water transport delay time from *m-th* reservoir to *i-th* reservoir
$M_{u,i}$	Number of upstream hydro plants directly above hydro plant i
T	Concerned time interval (24 hrs)
I	Number of hydro plants
K_1	The fixed term of O&M costs of pumped-storage plant
K_2	The coefficient of variable term in O&M costs of pumped-storage plant

I. INTRODUCTION

THE deregulation of the electric power industry has created energy markets in which power producers compete with each other to sell the amount of power that maximizes their profit [1]. The generation expansion problem is one of the problems that power producers face with in this new environment. A power producer must evaluate the economic justification of its generation expansion planning before commencing to construct.

In this paper, the generation expansion of a price-taker hydro generating company will be investigated by means of pumped-storage plant construction. This company comprises several cascaded hydro plants along a river basin. Assuming the existence of a suitable zone as a natural reservoir, the hydro producer would like to evaluate the economic justification of pumped-storage plant construction using the mentioned natural zone as upper reservoir and one of its hydro reservoirs as lower reservoir. Before commencing the construction of this pumped-storage plant, its economic merit must be evaluated. In order to reach this goal, the profits of pumped-storage operation in the possible markets such as energy and ancillary service markets should be determined. The steps of evaluating the economic justification are represented in the following:

Step 1: Determining the expected profit of hydro producer considering no pumped-storage plant by means of developing a self-schedule problem in a specific time interval.

Step 2: Determining the expected profit of hydro producer considering the pumped-storage plant by means of developing a self-schedule problem in the same time interval.

Step 3: Comparing the expected profits of hydro producer with and without the pumped-storage plant, and calculating the net profit of pumped storage plant in the considered time interval.

Step 4: Calculating the Internal Rate of Return (IRR) of this plan considering the calculated net profit of pumped-storage plant in a specific time interval, the life time of pumped-storage plant, the O&M costs, the inflation and interest rates.

Step 5: Comparing the calculated IRR and Minimum Acceptable Rate of Return (MARR), and determining whether the plan have economic merit or not.

In first two steps, it is essential to have an appropriate strategy to calculate the amount of profit. Hence, in this paper, a comprehensive approach to self-schedule of hydro producer with and without the pumped-storage construction is developed. The profit maximization problem faced with the hydro producer is therefore formulated and solved as a Mixed-Integer Non-Linear Programming (MINLP) problem. The rest of this paper is organized as follows. Section II is devoted to self-scheduling problem formulation of hydro producer. Section III illustrates the considered case study. The numerical results of self-scheduling problem and also economic study are represented in section VI. Finally, section V is dedicated on the conclusion of the paper.

II. FORMULATION OF SELF-SCHEDULING PROBLEM

The self-scheduling problem is executed to optimally determine the hourly production bids in the energy and the ancillary service markets to maximize company's profit while all the operational constraints are satisfied. The analysis will be performed considering the energy, the spinning reserve and the regulation markets, simultaneously. In the case of hydro plants, the production costs are negligible. The start-up costs have real impact on the short-term scheduling of hydro plants. Start-up costs are mainly caused by the increased maintenance of windings and mechanical equipment and by malfunctions of the control equipment [2-3]. However, in the case of pumped-storage plant, the O&M costs are considered using fixed and variable terms [4]. The objective function and respected constraints of self-scheduling problem over a concerned time interval can be represented by (1)-(30) assuming the incomes, payments, start-up and O&M costs of hydro generating company.

The first six terms of (1) represent the revenues of hydro generating company earned by participating in energy, spinning reserve and regulation markets, respectively. As discussed in section II, the company expects to receive extra income when it is called to generate in the ancillary service markets. These expected revenues are shown by seventh to tenth terms. Finally, two last terms show the start-up and O&M costs of company.

Maximize:

$$\sum_{t=1}^{T}\sum_{i=1}^{I}P_{he,i}(t).\lambda_e(t)+\sum_{t=1}^{T}(P_{pe,s}(t)-P_{pe,p}(t)).\lambda_e(t)+\sum_{t=1}^{T}\sum_{i=1}^{I}P_{hs,i}(t).\lambda_s(t)+\sum_{t=1}^{T}(P_{ps,s}(t)+P_{ps,p}(t)).\lambda_s(t)+\sum_{t=1}^{T}\sum_{i=1}^{I}P_{hr,i}(t).\lambda_r(t)$$
$$+\sum_{t=1}^{T}P_{pr}(t).\lambda_r(t)+P_{del.}.\sum_{t=1}^{T}\sum_{i=1}^{I}P_{hs,i}(t).\lambda_{spot}(t)+P_{del.}.\sum_{t=1}^{T}(P_{ps,s}(t)+P_{ps,p}(t)).\lambda_{spot}(t)+(P_{r,up}-P_{r,down}).\sum_{t=1}^{T}\sum_{i=1}^{I}P_{hr,i}(t).\lambda_{spot}(t) \quad (1)$$
$$+(P_{r,up}-P_{r,down}).\sum_{t=1}^{T}P_{pr}(t).\lambda_{spot}(t)-\sum_{t=1}^{T}\sum_{i=1}^{I}SU_i(t)-\sum_{t=1}^{T}\left\{K_1+K_2.\left[(P_{pe,s}(t)+P_{pe,p}(t)+(P_{r,up}-P_{r,down}).P_{pr}(t)+P_{del.}.(P_{ps,s}(t)-P_{ps,p}(t))\right]\right\}$$

s.t.

$$\underline{X}_i \le x_i(t) \le \overline{X}_i \quad (2)$$
$$\underline{X}_p \le x_p(t) \le \overline{X}_p \quad (3)$$
$$\underline{U}_i.d_i(t) \le u_i(t) \le \overline{U}_i.d_i(t) \quad (4)$$
$$\underline{U}_p.d_s(t) \le u_p(t) \le \overline{U}_p.d_s(t) \quad (5)$$
$$\underline{V}_i.d_i(t) \le v_i(t) \le \overline{V}_i.d_i(t) \quad (6)$$
$$P_{h\exp,i}(t)=P_{he,i}(t)+P_{t,i}(t)+P_{del.}.P_{hs,i}(t)+(P_{r,up}-P_{r,down}).P_{hr,i}(t) \quad (7)$$
$$P_{p\exp}(t)=P_{pe,s}(t)+P_{del.}.P_{ps,s}(t)+(P_{r,up}-P_{r,down}).P_{pr}(t) \quad (8)$$
$$x_i(t+1)=x_i(t)+y_i(t)+z_i(t)-u_i(t)-v_i(t) \qquad i\notin lower\ reservoir\ of\ pumped-storage\ plant \quad (9)$$
$$x_i(t+1)=x_i(t)+y_i(t)+z_i(t)+u_p(t)-u_i(t)-v_i(t)-w_i(t) \qquad i\in lower\ reservoir\ of\ pumped-storage\ plant \quad (10)$$
$$x_p(t+1)=x_p(t)+w_i(t)-u_p(t) \quad (11)$$
$$z_i(t)=\sum_{m=1}^{M_{u,i}}(u_m(t-\tau_{m,i})+v_m(t-\tau_{m,i})) \quad (12)$$
$$w_i(t)\le Min[x_i(t),\overline{X}_p-x_p(t),w_{\max}] \quad (13)$$
$$P_{h\exp,i}(t)=\phi_{h,i}(x_i,u_i,t)=d_i(t).(c_{1,i}.x_i^2(t)+c_{2,i}.u_i^2(t)+c_{3,i}.x_i(t).u_i(t)+c_{4,i}.x_i(t)+c_{5,i}.u_i(t)+c_{6,i}) \quad (14)$$
$$P_{p\exp}(t)=\phi_{p,s}(x_p,u_p,t)=d_s(t).(c_{1,ps}.x_p^2(t)+c_{2,ps}.u_p^2(t)+c_{3,ps}.x_p(t).u_p(t)+c_{4,ps}.x_p(t)+c_{5,ps}.u_p(t)+c_{6,ps}) \quad (15)$$
$$\phi_{p,p}(x_p,w_i,t)=d_p(t).(c_{1,pp}.x_p^2(t)+c_{2,pp}.w_i^2(t)+c_{3,pp}.x_p(t).w_i(t)+c_{4,pp}.x_p(t)+c_{5,pp}.w_i(t)+c_{6,pp}) \quad (16)$$
$$\phi_{p,p}(x_p,w_i,t)=P_{pe,p}(t)+\sum_{i=1}^{I}p_{t,i}(t) \quad (17)$$
$$P_{hr,i}(t)\le P_{he,i}(t) \quad (18)$$

$$P_{pr}(t) \le P_{pe,s}(t) \quad (19)$$

$$0 \le P_{hr,i}(t) \le \phi_{h,i}(x_i, \overline{U_i}, t)/2 \quad (20)$$

$$0 \le P_{pr}(t) \le \phi_{p,s}(x_p, \overline{U_p}, t)/2 \quad (21)$$

$$P_{pe,s}(t) + P_{ps,s}(t) + P_{pr}(t) \le \phi_{p,s}(x_p, \overline{U_p}, t) \quad (22)$$

$$P_{he,i}(t) + P_{hs,i}(t) + P_{hr,i}(t) \le \phi_{h,i}(x_i, \overline{U_i}, t) \quad (23)$$

$$SU_i(t) = SU_i.d_i(t).(1 - d_i(t-1)) \quad (24)$$

$$0 \le P_{ps,p}(t) \le d_p(t).P_{pe,p}(t) \quad (25)$$

$$d_s(t-1) + d_p(t) \le 1 \quad (26)$$

$$d_p(t-1) + d_s(t) \le 1 \quad (27)$$

$$d_s(t) + d_p(t) \le 1 \quad (28)$$

$$X_i^{end} = \beta.X_i^0 \quad (29)$$

$$X_p^{end} = \beta.X_p^0 \quad (30)$$

Hydro and pumped-storage plants must adjust their water storage, discharge and spillage in the acceptable ranges. These cases are applied by (2)-(6). The amount of hourly expected power which must be generated to response in the energy, spinning reserve and regulation markets by hydro and pumped-storage plants are represented by (7) and (8), respectively. The hourly water amount of each hydro plant in its reservoir can be calculated by (9). This equation is modified by (10) for hydro reservoir which is considered as lower reservoir of pumped-storage plant. The hourly water amount of upper reservoir of pumped-storage plant can be calculated by (11). In equations (9)-(10), the input water of each hydro plant is categorized to independent and dependent inflows. The natural inflow of each hydro plant is considered as independent inflow, while the dependent inflow is caused due to discharge and spillage of upstream hydro plants. The amount of dependent inflow of each hydro plant considering water transport delay time is determined by (12). The water is transported between lower and upper reservoirs of pumped-storage plant through a special pipeline named "penstock". As it is presented in (13), the hourly amount of water charge of pumped-storage plant is limited due to the available water in lower reservoir, the vacant capacity in upper reservoir and penstock's capacity (w_{max}). Equations (14)-(15) characterize the hydro-electric generation function of each hydro plant and pumped-storage plant, respectively [5]. Also, the amount of required power of pumped-storage in its charging mode is determined by (16) which must be provided by internal generated power of company or by purchasing from energy market referred in (17). In order to ensure regulation-down service, constraints (18)-(19) are applied. In (20)-(21), the lower and upper limits of regulation power which can be produced by hydro and pumped-storage plants are presented where the upper limit is considered as half of maximum capability of power generation, in order to response to both regulations up and down requests.

The lower limit of water stored in each hydro plant and in upper reservoir of pumped-storage plant must be adjusted to allow the company to response to the worst condition from the energy stored level point of view. The worst condition may occur when company is called to generate in the spinning reserve and the regulation-up markets, simultaneously. Eqs. (22)-(23) are applied to consider this condition. The start-up times of each hydro plant are identified in (24). Also, the upper limit of spinning reserve power in purchasing mode of pumped-storage plant is represented by (25). In (26)-(27), changeover times of the pumped-storage plant are modeled. The changeover time of a pumped-storage plant is typically between 15 to 30 minutes. For a DA market operated on an hourly basis, this constraint translates to a plant having a buffer of at least one hour at zero generation between selling and purchasing modes [7]. Eq. (28) is considered to eliminate conflict between different modes in a specific hour. Eqs. (29)-(30) are contemplated in order to reserve enough energy stored in each hydro plant and upper reservoir of pumped-storage plant for the subsequent time interval. The parameter β adjusts the amount of water that should be stored for the subsequent time interval. If lower prices for the next time interval are forecasted, the company will choose a low value for β. This parameter can be varied while the stored water constraints are satisfied.

The optimization problem in (1)-(30) is a *MINLP* problem that can be solved by any commercial software. In this paper, it will be solved using *SBB* [6] under *GAMS* [7].

III. Case Study

The numerical results which are presented in this section consist of self-scheduling for a price-taker hydro producer with and without considering the pumped-storage plant in day-ahead energy, spinning reserve and regulation markets. The time horizon comprises of 24 hrs. The test hydro company comprises four cascaded hydro plants one of which is regulating plant. Also, the third hydro plant is considered as lower reservoir of pumped-storage plant. The company's topology is shown in Fig. 1.

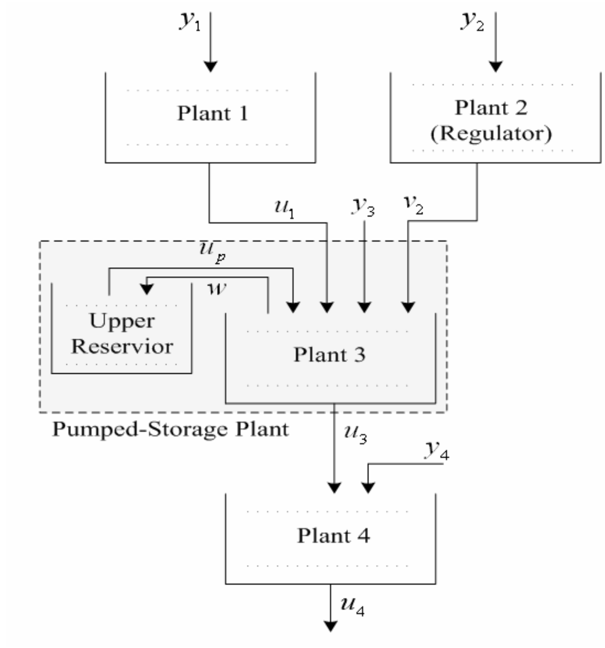

Fig. 1.The topology of hydro generating company

TABLE I
COEFFIECIETS OF POWER GENERATION/CONSUMPTION FUNCTION OF PLANTS

	C_1	C_2	C_3	C_4	C_5	C_6
Plant 1	-0.001	-0. 1	0.01	0.40	4.0	-30.0
Plant 3	-0.001	-0. 1	0.01	0.30	3.0	-30.0
Plant 4	-0.001	-0. 1	0.01	0.45	4.5	-30.0
Pumped-Storage (discharging)	-0.001	-0. 1	0.01	0.42	4.2	-30.0
Pumped-Storage (charging)	-0.001	-0. 1	0.01	0.70	7.0	-30.0

TABLE II
FORECASTED PRICES AND INDEPENDENT INFLOWS

Hour	$\lambda_e(t)$	$\lambda_s(t)$	$\lambda_r(t)$	$y_1(t)$	$y_2(t)$	$y_3(t)$	$y_4(t)$
1	55.3	43.2	34.0	10	28	20	20
2	50.0	30.0	10.0	9	28	20	20
3	45.7	27.5	10.0	8	29	10	20
4	44.0	29.2	10.0	7	25	10	18
5	42.9	29.2	10.0	7	22	5	18
6	42.6	29.2	10.0	7	20	4	0
7	46.9	44.1	10.0	8	16	5	0
8	56.8	39.9	51.1	9	14	5	0
9	70.6	28.5	60.0	10	12	1	0
10	75.9	20.2	57.3	10	10	1	0
11	70.9	22.3	65.0	10	8	1	0
12	77.0	19.1	62.5	10	8	1	0
13	73.4	13.2	73.0	0	8	1	0
14	75.9	23.4	70.0	0	8	1	0
15	67.8	30.0	65.0	0	8	1	0
16	66.0	30. 9	62.5	0	8	1	0
17	64.8	30.0	51.8	0	8	1	0
18	65.2	30.0	49.8	0	8	1	0
19	68.6	30.0	57.3	0	8	1	0
20	72.5	30.0	69.4	0	16	1	0
21	77.7	22.7	66.9	0	20	1	18
22	75.9	28.2	66.9	0	28	1	20
23	68.4	28.6	61.4	0	28	20	20
24	70.3	27.5	60.0	0	28	20	20

TABLE III
PLANTS DATA

	$\underline{X}$	$\overline{X}$	$\underline{U}$	$\overline{U}$	X^0	$\underline{V}$	$\overline{V}$
Plant 1	80	*150*	5	15	100	0	0
Plant 2	60	*120*	0	0	80	10	30
Plant 3	50	*300*	10	30	170	0	0
Plant 4	70	*160*	13	25	100	0	0
Pumped-Storage	40	*200*	10	30	100	0	0

The coefficients of generation function for each hydro plant and pumped-storage plant as well as consumption function of pumped-storage plant are represented in Table I. The assumed forecasted prices of the energy, the spinning reserve and the regulation markets are shown in Table II. Price data are adopted from electric energy market of Mainland, Spain [8] with a few adjustments. Also, Table II shows the forecasted hourly independent water inflow for each hydro plant. Bounds of reservoir's storage, water discharge, water spillage and initial storage for each hydro plant and upper reservoir of pumped-storage plant are depicted in Table III. The time delays for water transportation are $\tau_{1,3} = 2$, $\tau_{2,3} = 3$ and $\tau_{3,4} = 4$. The probability of calling plants to generate energy in the spinning reserve market ($P_{del.}$) is assumed to be 3% [9]. Also, the probabilities of regulation-up and regulation-down states are considered 40% and 35% respectively, which seem rational assumptions [10].

The start-up costs of plant1, plant2 and plant 3 are considered to be \$550, \$1500 and \$1000, respectively. The adjusting constant (β) is assumed to be 1. Also, the maximum penstock transfer capability (w_{max}) is assumed to be 25MW.

The random-based method shown by (31) is used to forecast the hourly spot price [11-13]. The hours between 9 and 18 are contemplated as the peak period. In order to present the spike price in the peak hours, a number of spikes are randomly generated using Frechet distribution [14].

$$\lambda_{spot}(t) = \begin{cases} (1+\gamma)\lambda_e(t) & 0 \le \gamma \le 0.25 \quad t \in [9,18] \\ (1+\mu)\lambda_e(t) & -0.1 \le \mu \le 0.1 \quad otherwise \end{cases} \tag{31}$$

IV. Numerical Results

A. Self-scheduling problem results

Based on self-scheduling problem results, the maximum expected daily profits of hydro producer without and with considering of pumped-storage plant are \$248816.954 and \$269645.274, respectively. Hence, the expected daily profit of hydro producer is increased as much as 9% when the pumped-storage is considered. The more detailed results of self-scheduling problem for a similar case study are available on [15].

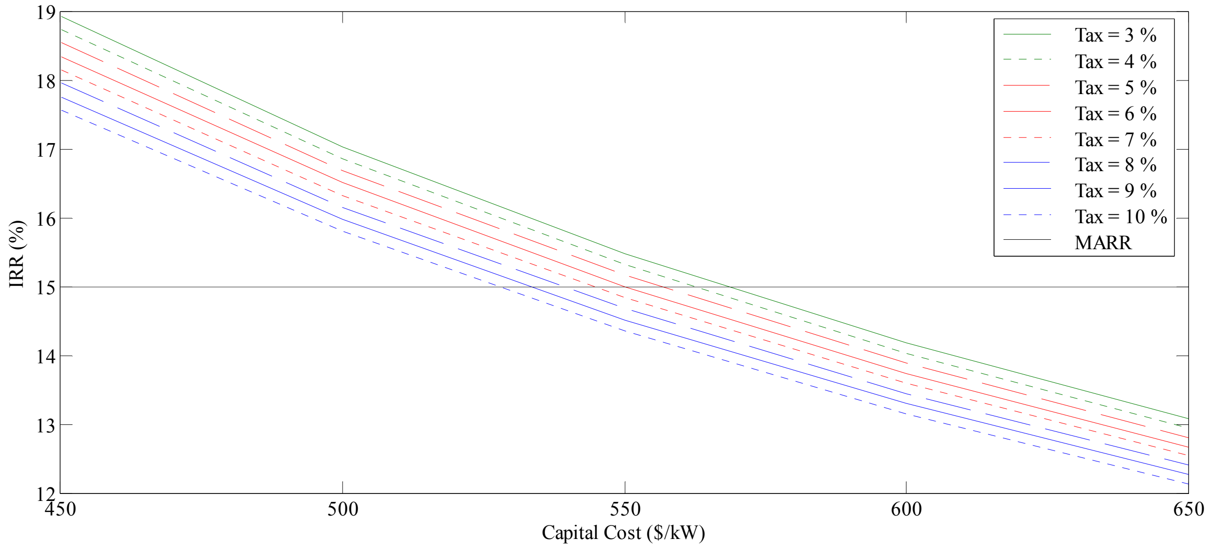

Fig. 2. The IRR versus different amounts of capital cost and tax rate

B. Economic study results

After determining maximum expected daily profits of hydro producer without and with considering of pumped-storage plant, the economic merit of pumped-storage plant construction should be investigated during its life time [16]. Here, the expected annual profit of pumped-storage plant is first estimated considering utilization factor, depreciation loss, and tax. Then, its Internal Rate of Return (IRR) as economic merit indicator is determined during its life time. The pumped-storage plant construction has economic merit if and only if the calculated IRR is greater than Minimum Acceptable Rate of Return (MARR). The MARR in assumed to be 15%. The annual deprecation loss rate is assumed to be 1% of annual profit.

The results of this economic study are represented in Fig. 2 considering the different amounts of capital cost and tax rate. Each of the trends in this figure shows the IRR versus the different levels of tax rate. Hydro producer prefers to invest on the pumped-storage plant if the IRR is higher than the MARR. According to Fig. 2, when the annual tax rate is 10% of annual profit, investment on the pumped-storage plant will be economically justified if the capital cost of constructing the pumped-storage plant is less than 528$/KW. By considering the lower tax rate, the pumped-storage plant construction can be financially justified versus higher capital cost. For instance, this amount is approximately 534$/KW, 539$/KW, 545$/KW, 550$/KW, 557$/KW, 561$/KW and 569$/KW when the tax rate is considered as 9, 8, 7, 6, 5, 4 and 3 percent, respectively.

V. Conclusions

In this paper, an economic viability of generation expansion of a hydro producer was investigated in the case of constructing a pumped-storage plant. A self-scheduling problem for considered hydro producer without and with considering pumped-storage plant was performed in order to calculate the maximum potential of expected profit in a specific time interval. Then, the economic merit of pumped-storage plant during its expected life time was investigated using determination of Internal Rate of Return (IRR). This analyze indicates the status of economic merit versus different amounts of capital cost and tax rate.

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