Optimal Scheduling of Hydropower Plant with Uncertainty Energy Price Risks

C. J. Zhu, J. Z. Zhou, *Senior Member, IEEE*, J. J. Yang, and W. Wu

***Abstract*--This paper presents a methodology for the development of generation strategies of hydropower plant in a competitive electricity market. Initially, the problem is constructing as a two level optimization problem by time scales, where at upper level use the Markov decision in the sequential strategy to establish the sequential model of hydropower generation strategy. At the lower level, an optimal generation strategy model under the risks of water inflow and day-ahead electricity prices uncertainties, which are dividend into Ω^{l} scenarios, is established to modify the upper level's generation strategies. Duel stochastic dynamic programming are employed in the power generation process of each hydropower plants so that the maximization expected return can be reached, each level's generation strategies and contract quantities are obtained. The real case studies shown the proposed models are rational and feasible.**

***Index Terms*--Electricity market, cascade hydropower plant, optimization scheduling, multi-time Markov decision processes, electricity prices, risk.**

I. Nomenclature

n	Time period of trading in the contract market $n=\{1,2,\cdots,N\}$
t	Time period of trading in the day-ahead market, $t=\{t_1,t_2,\cdots,t_T\}$.
d^l	Vector of day-ahead market decision.
d^u	Vector of contract market decision.
$p_c(n)$	Electricity price for contract in time period n (RMB/MWh).
$p_d(t,n)$	Average day-ahead electricity price in time period t for contract period n (RMB/MWh).
$Q(n)$	Forecasted load demand of hydro plants from PX in time period n (MW).
$Q_c(n)$	Quantity of trading in the contract market in time period n (MWh).
$Q_d(t,n)$	Quantity of trading in the day-ahead market in time period t for contract period n (MWh).
$X(t,n)$	Maximum generation of a hydropower producer in time period t for contract period n
C	Unit generation cost (RMB/MWh).
V_n	Reservoir vector of plant m in the time period n
RQ_n	Water inflow of plant m in the time period n
VQ_n	Generation discharge of plant in the time period n
$\overline{N_n}$	Maximum generation of plant in the time period n.
$\underline{N_n}$	Minimum generation of plant in the time period n.
$\overline{U_n}$	Maximum spillage of plant in the time period n.
$\underline{U_n}$	Minimum spillage of plant in the time period n.

This work was supported in part by National Science Foundation of China under Grant No. 50579022 and .50539140.

C. J. Zhu is with the College of Hydropower and Information Engineering of Huazhong University of Science and Technology (HUST), Wuhan, Hubei, 430074, China (e-mail: zhu_chengjun @ctgpc. com. cn).

J. Z. Zhou is with the College of Hydropower and Information Engineering of Huazhong University of Science and Technology (HUST),Wuhan, Hubei, 430074, China (e-mail: Prof.zhou.hust@ 263. net).

J. J Yang is with the College of Hydropower and Information Engineering of Huazhong University of Science and Technology (HUST),Wuhan, Hubei, 430074, China (e-mail: yangjunjie@vip.l63. com)

W. Wu is with the College of Hydropower and Information Engineering of Huazhong University of Science and Technology (HUST),Wuhan, Hubei, 430074, China (e-mail: weiwu208@hotmail. com)

II. Introduction

TRADITIONALLY hydropower plants optimal scheduling is based on the minimization of operational costs or the maximization of quantity generation and the aim of a reservoir management in a conventional power system is to minimize expected costs while maintaining an adequate security of supply [1]. However, the deregulation of the electricity industry is giving way to a global trend toward the commoditization of electric energy; this trend has recently intensified in China, where market forces have pushed legislators to begin removing artificial barriers that shielded electric utilities from competition [2]. With the deregulation of electricity markets, the hydropower producers have to change their focus from reliable and cost-efficient supply of electricity to more profit oriented and competitive objectives [3].

Hydropower is different from other generation in the sense that hydropower management will faces different types of risk including spot electricity price, generation risk by inflow and load demand uncertainty, et.al.[4]. In paper [5], a stochastic dynamic programming model for the joint hedging and generation planning of hydropower system discussed. Hedging by future contracts and the medium-term generation scheduling is presented by using integrated risk management and contract management in [6]. An electricity planning model which deals with uncertainty and its associated risk at

1-4244-0111-9/06/$20.00©2006 IEEE.

two levels was presented in [7] and introduced an approach called stochastic dual dynamic programming that can be used with multi-reservoir system The model presented in [8] can be applied to production scheduling but not directly to the case of hydropower system and considered the long-term generation scheduling of hydropower system by a stochastic dynamic programming.

Hydropower producers that management hydropower energy with subjected to some constraints can move energy between periods by adjusting the rates of release from reservoirs. Water in a reservoir can be used now, or it can be stored for use in the future, the same choice of using water straightaway or storing for later use arises at any point in time. Hence the water may be used to generate electricity for spot market selling in any future period [9, 10]. At the first level, by minimizing environmental risk through a multiple-criteria model and at the second level, by performing a risk analysis consistent with the multiple criteria model [11].

In order to hedging risk of electricity prices and water inflow uncertainties in different seasons (water-rich and dry sessions) and getting profits in the electricity market, in this study, we model hydropower scheduling as a multi-time scale Markov decision process [12,13,14] and the hydropower portfolio decision model has two level decisions. At upper level with contract market, by using Markov decision process to establish the hydropower contracts trading. At the lower level in day-ahead market, an optimal generation management model under the risks of forecasted water inflow and electricity prices uncertainties is established to modify the upper level's generation strategies. The decision is to be made on a weekly for both the generation scheduling and forward bilateral contracts.

In the present work, an approach based on two-level Markov decision process is employed in the section III. Section IV illustrates an example model and followed by concluding in Section V.

III. PROBLEM FORMULATION

Hydropower producers are faces risks of electricity price fluctuations and inflow uncertainties, in the flood (water-rich) season, hydropower management need to take into account flood control, power generation, and shipping in the reservoir. Therefore, hydropower producers in the market for the power transactions can choose whether or not trading in the day-ahead market, in order to obtain optimum benefits in all sessions. In the electricity market, we assume that hydropower producers are relatively price takers or with little market power and having no opportunities in influencing electricity prices to raise profit significantly.

A. Energy Price uncertainty Risks

The initial decision-making, while power generation business through the historical data to predict the future electricity price trading hours of electricity price and the spot contract to the electricity price decision-making two of the best market portfolio transactions, however, the actual cash transactions electricity price is very random volatility, resulting in spot electricity price forecast accuracy is limited, but two market electricity price differences between different levels of vulnerability and, therefore, generating business transactions must be in the initial analysis of market-anticipated arbitrage opportunities, and enhance their own competitiveness in the market, gain more profits. The electricity price of day-ahead market under long-term contracts for three to quantify the level of different levels of the corresponding probability different [15]. Table I shows the probability of classified electricity prices.

$$p_d(t,n)=\begin{cases}\overline{P_h} & (p_d(t,n)>p_c(n)+\delta)\\ \overline{P_m} & (p_c(n)-\delta\le p_d(t,n)\le p_c(n)+\delta)\\ \overline{P_l} & (p_d(t,n)<p_c(n)-\delta)\end{cases} \quad (1)$$

TABLE I
THE POSSIBLE PROBABILITY OF THE UNCERTAINTY ELECTRICITY PRICES

	Higher prices	Normal prices	Lower prices
Variable	$\overline{P_h}$	$\overline{P_s}$	$\overline{P_l}$
Probability	λ_1	λ_2	λ_3

When actual cash transactions during the electricity price high, and the initial decision-making is a clear deviation forward electricity price contract $(\overline{P_h}\ge p_c(n)+\delta)$, the probability of the emergence of spot electricity price peak electricity price than a low probability ($\lambda_1>>\lambda_2$); Alternatively, the actual cash transactions during the electricity price is low, the initial decision-making forward contracts tariff higher than the actual spot electricity price $(\overline{P_l}\le P_c(n)-\delta)$. The probability of the emergence of spot electricity price peak electricity price is much less than the low probability $(\lambda_1<<\lambda_2)$, the arbitrage opportunities will be created. From the macro point of the electricity market analysis, market participants (including power generation companies, electricity companies to buy) arbitrage behaviors makes the tariff relations between the two market interaction between benefit from the elimination of tariff market.

B. Markov Decision Process of hydropower scheduling

The multi-time scale Markov decisions made in the upper level affect the decision making process of the lower level but the lower level decisions do not affect the upper lever decision performance [13]. In each level, multi-stage decision making at every stage of decision making are required, thus making the whole process optimization, multi-stage selection is not an arbitrary decision, and it depends on the current state facing [11]. Suppose the state space set of cascade hydro plants trading in the contract market is Ω^u , action set is Λ , the decision making period is n , state variable $i_n\in\Omega^u$, action variable $\lambda_n\in\Lambda$, the probably of state i_n transaction to state i_{n+1} is $P^u(i_{n+1}|i_n,\lambda_n)$, the lower lever decision-making is lagging behind the upper lever decisions by time scale.

In the lower level of day-ahead market, suppose the state space set is Ω^l, action set is A and $\Omega^u \cap \Omega^l = \Phi$, $\Lambda \cap \mathrm{A} = \Phi$, this means that hydropower trading with the contract market and day-ahead market are independent in and state space and decision making. Let $t \in \{t_1, t_2, \cdots, t_T\}$ on behalf of lower stage period in decision-making. T is the lower fixed period. After the contract trading in the upper stage n, the lower stage t_1 day-ahead decision making start. The initial state of upper decision-making is $i_1 \in \Omega^u$, action $\lambda_1 \in \Lambda$, and then the next state i_2 will be determined by the transaction probability P^u. For the lower level initial state $x_{t_1} \in \Omega^l$, with the evolution of time period $t_1, t_2, \cdots, t_T$, when the state is x_{t_1} and action is $\gamma \in \mathrm{A}$, the probability of state x_{t_1} transaction to state x_{t_2} is $P^l(x_{t_2} | x_{t_1}, r, i_1, \lambda_1)$, the revenue is $R^l(x_{t_1}, r, i_1, \lambda_1)$, until the completion of a decision making stage time evolution t_T, see Fig.1.

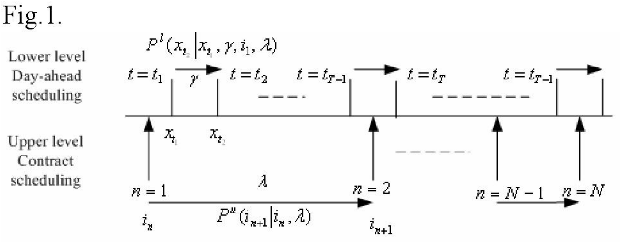


Fig. 1. Two level Markov decision evolution process

C. *Upper lever decision (contract scheduling)*

We consider an electricity producer whose actions cannot affect the market prices, its generation and trading strategy of power do not change the market prices that are assumed to be exogenous variable. In this paper, time period of upper lever of contract market is determined in weekly, which is trading before the decisions of day-ahead market. For each time period $n \in \{1, 2, \cdots, N\}$, the state space set of contract scheduling is $\Omega^u = \{p_c(1), p_c(2), \cdots, p_c(N)\}$ (the retune of hydropower producer is determined by the contract prices of the each period) and action set is $\Lambda = \{Q_c(1), \cdots, Q_c(N)\}$ (this is determined by the generation planning strategies of each period). The probability of state $p_c(n)$ transition to $p_c(n+1)$ is $P^u(p_c(n+1) | p_c(n), Q_c(n))$ (conditional probability of action $Q_c(n)$), and the revenue of the contract scheduling in the upper level is $R^u(p_c(n), Q_c(n))$.

The optimal generation scheduling and the volume of bilateral contracts to be signed for each time period with the objective of gaining maximum revenue, the revenue in each period is given by

$$R(n) = p_d(n)Q_d(n) + p_c(n)Q_c(n) \tag{2}$$

Summing up the revenues for each period, the objective function is obtained as

$$\begin{aligned} \max \sum_{n=1}^{N} R(n) &= \sum_{n=1}^{N} p_d(n) Q_d(n) \\ &+ \sum_{n=1}^{N} \sum_{\Omega^U} P^u(p_c(n+1) | p_c(n), Q_c(n)) p_c(n) Q_c(n) \end{aligned} \tag{3}$$

where $Q_c(n) = Aq(n)N(n)$. A is generation coefficient, $N(n)$ is the generation quantities of plant in the time period n

The cost of hydro generation depends on the producers sub jective expectations regarding future spot prices and inflow co nditions.

Constraints:

1) Capacity constraint balance

$$Q_d(n) + Q_c(n) = Q(n) \tag{4}$$

2) Water balance and reservoir limits

Water reservoir level of cascade hydropower plants at the end of a period depends on each water reservoir levels at the beginning of the period, inflows and the discharge of power generation.

$$V_{n+1} = V_n + RQ_n - VQ_n - VQ_n^{\Omega^u}. \tag{5}$$

$$\underline{V_n} \le V_n \le \overline{V_n}. \tag{6}$$

Where $VQ_n^{\Omega^u}$ is the current generation discharge in the scenario Ω^u after the contract price and inflow are observed in the time period n.

3) Generation upper and lower limit

$$\underline{N_n} \le N_n \le \overline{N_n}. \tag{7}$$

4) Spillage constraint

$$\underline{U_n} \le U_n \le \overline{U_n}. \tag{8}$$

D. *Day-ahead Stochastic Scheduling with Recourse*

The period of lower lever is day-ahead scheduling in the day-ahead market. The state space in the day-ahead market is $\Omega^l = \{p_d(t_1, 1), \cdots\cdots, p_d(t_T, N)\}$, Action set is $\mathrm{A} = \{S(t_1, 1), \cdots, S(t_T, N), K(t_1, 1), \cdots, K(t_T, N)\}$ (where decision variable $S(n,t)$ and $K(n,t)$ are quantity of selling and purchasing in time period $t \in \{t_1, t_2, \cdots; t_T\}$ for contract period n respectively. Let the initial state is $p_d(t_1, n) \in \Omega^l$, and action $\gamma \in A$, through the time period $t_1, t_2, \cdots, t_T$, the probability of state $p_d(t_1, n)$ transition to state $p_d(t_2, n)$ is $P^l_{1,t_1}(p_d(t_2, n) | p_d(t_1, n), r, p_c(n), Q_c(n))$, and the revenue is $R^l(p_d(t_1, n), \gamma, p_c(n), Q_c(n))$.

It is customary in stochastic programming to assume that the probability distribution of random parameters is known. For a decision maker choosing to incorporate the uncertainty into some stochastic programming model, the uncertain parameters must be specified. Therefore, a more accurate and appropriate model is obtained. If some effort is put into the estimation of the probability distribution of random parameters. Moreover, forecasting is vital, as the decision will be based on the price and inflow forecasting.

The goal was designed to gain the best decision-making trading sets $d^u \in \Lambda$ and $d^l \in A$, so that the total expectations revenue $V(d^n, d^l)$ reaches the maximum value.

$$V(d^u, d^l) = \max_{d^u \in A} \max_{d^l \in \wedge} E\{\sum_{n=1}^{N} (R_n^u(d^u, P_n^u) + R_n^l(d^l, P_n^l))\} \cdot \quad (9)$$

According to the power scheduling of the contracts, hydropower cumulative portfolio revenue in the two markets is:

$$\begin{aligned} R(T,n+1) = R(T,n) + \sum_{t=t_1}^{t_T} (S(t,n)(p_d(t,n)) - W_c C) \\ - K(t,n)(p_d(t,n)) + W_c C) \end{aligned} \quad (10)$$

Where $0 \le W_c \le 1$ is a transaction ratio compared to the unite generation cost. The initial transaction state is $p_d(t,1)$ and $R(T,1)$, if $t_1(T) \le n \le t_T(T)$, the upper lever for hydropower contract trading is $R(T,n) = Q_c(n) p_c(n)$. So, hydropower portfolio revenue of the two markets is:

$$\begin{aligned} &\max \sum_{n=1}^{N} R(n) \\ &= \sum_{n=1}^{N} \{ \sum_{\Omega^l} \sum_{t=t_1}^{t_T} P_{1,t_1}^l S(t,n)(p_d(t,n) - W_c C) \\ &\quad - \sum_{\Omega^l} \sum_{t=t_1}^{t_T} P_{1,t_1}^l K(t,n) p_d(t,n) + W_c C) \} \\ &\quad + \sum_{n=1}^{N} \sum_{\Omega^U} P^u (p_c(n+1) | p_c(n), Q_c(n)) p_c(n) Q_c(n) \end{aligned} \quad (11)$$

Constraints:

1) Capacity constraint balance

$$Q(n) = Q_c(n) + \sum_{t=t_1}^{t_T} (K(t,n) - S(t,n)) \quad (12)$$

2) Water balance and reservoir limits

$$V_{n+1} = V_n + RQ_n - VQ_n - VQ_n^{\Omega^u} - VQ_n^{\Omega^l} \quad (13)$$

$$\underline{V_n} \le V_n \le \overline{V_n} \ . \quad (14)$$

Where $VQ_n^{\Omega^l}$ is the current generation discharge in the scenario Ω^l after the uncertainty day-ahead price and inflow are observed in the time period n .

3) Generation upper and lower limit

$$\underline{N_n} \le N_n \le \overline{N_n} \ . \quad (15)$$

4) Spillage constraint

$$\underline{U_n} \le U_n \le \overline{U_n} \ . \quad (16)$$

E. Solution Method

Hydropower operation is a complex nonlinear optimization problem and has the links of inflow and electricity prices [16]. In the models (11) with constraints (12)-(15), the day-ahead market price and inflow to the reservoirs are uncertain variables. For each period in the contract market, the day-ahead prices are given as forecasted data within the maximum and minimum prices, and given for Ω^l scenarios. Duel stochastic dynamic programming is employed in the power generation process of each hydropower plants so that the maximization expected revenue can be reached, the portfolio management algorithm of hydropower in the contract market and day-ahead market decision process is illustrated in Fig. 2.

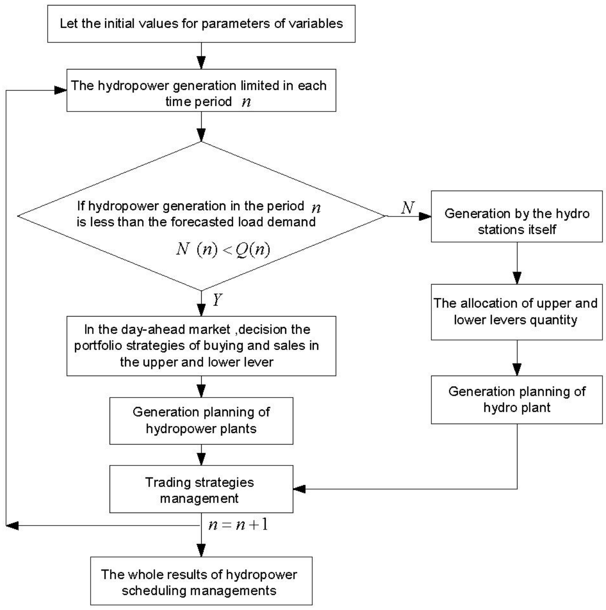


Fig. 2: Optimal scheduling programming management of hydropower plant

IV. Optimal Scheduling

A. Case Study

The purpose of the case study is to illustrate the hydropower portfolio management model with Fengtan station of China. Fengtan reservoir located in the domain of Yuanling county down of You river, and 45 kilometers away from the center of Yuanling. The reservoir drainage area is 17500 square kilometer and occupies 94.4% of the whole You river area. Fengtan reservoir belongs to seasonal regulation reservoir and the water inflow data from year 1998 to 1999 shown in figure 2. The water supply of Yuanling county area depends highly on Fengtan reservoir and the weekly water flow forecast helps the operators to well prepare for the future scheduling decisions.

In the model, the period starting from the week 35 of 1998 (after this week, the water inflow is decreased in the later of the year) to the week 21 of 1999(in the later weeks, this is water rich season), to keep the model simple, time period is divided into eight period,each period including five weeks , the average inflow and electricity prices in each period are shown in Table II.

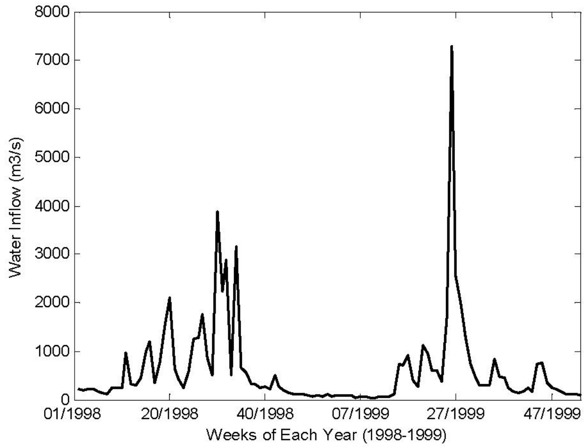


Fig.3 the inflow over a typical year of Fengtan reservoir from 1998 to 1999

TABLE II
FORECASTED AVERAGE WATER INFLOW AND PRICES IN EACH CONSIDERED PERIOD

Periods	Weeks	Year	Inflow (m3/s)	Price (RMB/KWh)
1	35-39	1998	417.43	0.28
2	40-44	1998	289.31	0.30
3	45-49	1998	119.89	0.32
4	50-01	1998/1999	80.89	0.32
5	02-06	1999	74.51	0.35
6	06-11	1999	53.63	0.32
7	12-16	1999	334.31	0.30
8	17-21	1999	733.26	0.26

The optimization of problem (11) considering the electricity price uncertainty including the contract prices and day-ahead electricity prices, the day-ahead electricity price is between the maximum and minimum electricity prices, which are shown in Table III. Suppose the probability of transition in the day-ahead market with the higher price is 0.3, the normal price is 0.4 and the lower price is 0.3. In the contract market, the transition probability $P^u \sim N(0.31, 0.0007)$ (where $N(0.31, 0.0007)$ is a Normal distribution function). Table IV shows the optimal scheduling results of the Fentan hydropower plant.

TABLE III
THE MAXIMUM AND MINIMUM ELECTRICITY PRICE AND INFLOW

Periods	Price		Inflow	
	Max. (RMB/KWh)	Min. (RMB/KWh)	Max. (m3/s)	Min. (m3/s)
2	0.38	0.18	847	86
3	0.42	0.18	201	67
4	0.46	0.18	180	7
5	0.48	0.18	109	39
6	0.45	0.18	121	5
7	0.42	0.18	1853	26
8	0.38	0.18	2716	169

TABLE IV
THE OPTIMAL SCHEDULING STRATEGIES OF THE CONTRACT AND DAY-AHEAD MARKETS

peri-od	Water level (m^3)	Generation inflow (m^3/s)	Spilla -ge (m^3/s)	Contract Generatio n (MWh)	Generat-ion (MWh)	Revenue (RMB $\times 10^6$)
1	205.00	255.195	0	136927.80	171159.75	65.04
2	207.04	367.418	0	0	246478.85	173.24
3	206.06	490.624	0	0	317277.07	209.99
4	201.16	12.338	0	0	7993.13	8.21
5	202.14	38.862	0	0	25358.42	12.50
6	202.63	17.552	0	0	11517.50	9.31
7	203.12	25.745	0	0	17279.86	179.91
8	207.04	895.495	0	0	586622.85	563.27

V. Conclusion

With the deregulation of electricity market in China, hydropower will be involved in the power market competition of the whole nation, combined with the national full use of water resources. Hydropower management is vital in the power trading and scheduling of hydro plants. A technique of portfolio management to optimize the expected revenue for a hydropower producer has been presented.

Using the proposed formulation, we have studied an optimal scheduling problem of Fengtan hydropower plant. The model described uses a portfolio management idea with two level Markov decision process approach to handle the stochastic behavior of the day-ahead prices and water inflow in the generations and emphasizing the water dry seasons optimal scheduling in the contract market and day-ahead market, and in the later dry season, using more water for the later dry sessions in order to the futures water rich seasons power generation.

Future improvements of the model include modeling of futures market trading within the same model by classify a newly multi-time scale with contract and day-ahead market, so that the water resources can be stored with future values and hydropower trading competition ability improved in the electricity market.

VI. Acknowledgment

The author would like to acknowledge Mr. Jianguo Zhu, a graduate student, for the experiment programming and testing of the theoretical modelling of hydropower plant.

VII. References

[1] M. V. F. Pereira and L. M. V. G. Pinto,"Stochastic optimization of a multi-reservoir hydroelectricity system: a decomposition approach," *Water Resource Research,* vol. 21, pp. 779-792, 1985.

[2] Rafal Weron." Energy price risk management, " *Physica A,* vol.285, pp. 127-134, 2000.

[3] Bi Y.X. and Li Z.H. "Corporate reform and restructuring of China largest hydro power enterprise,"*In Proc. 2004 IEEE International. Engineering Management Conference*, Singapore, pp.158-162,2004

[4] S. E. Fleten, W. T. Ziemba, and S. W. Wallace, "Portfolio management in a deregulated hydropower based electricity market," *in Proc. 3rd Int. Conf. Hydropower*, pp. 197–204, June 1997.

[5] M. Pereira, "Optimal stochastic operations scheduling of large hydroelectric systems," *Int. J. Electr. Power Energy Syst.*, vol. 11, pp.161–169, 1989.

[6] S.-E. Fleten, S. W. Wallace, and W. T. Ziemba, "Hedging electricity portfolios via stochastic programming," *in Decision Making Under Uncertainty: Energy and Power,* C. Greengard and A. Ruszczynski, Eds. New York: Springer-Verlag, 2002, vol. 128, IMA Volumes on Mathematics and Its Applications, pp. 71–93.

[7] Birger Mo, Anders Gjelsvik and Asbjorn Grundt." An Integrated risk management of hydro power scheduling and contract management," *IEEE Trans. Power Systems,* vol. 16, pp. 216-221, May 2001

[8] A. Gjelsvik, T. A. Røtting, and J. Røynstrand, "Long-term scheduling of hydro-thermal power systems," *In Proc. 2nd Int. Conf. Hydropower*, pp.539–546, June 1992.

[9] Zhou Hao, Zhang Quan and Zhang Fuqiang." Financial risk analysis in electricity market considering futures contracts," *Power System Technology*, vol.28, pp.53-57, 2004.

[10] G.B.Shrestha,Bikal Kumar, Pokharel,Tek, Tjing Lie and S.E.Fleten. "Medium term power planning with bilateral contracts," *IEEE Trans. Power Systems*, vol. 20, pp. 627-633, May 2005.

[11] Linares P. "Multiple criteria decision making and risk analysis as risk management tools for power systems planning," *IEEE Trans. Power Systems,* vol.17, pp. 895–900,2002.

[12] Hyeong Soo Chang; Fard, P.J.; Marcus, S.I.; et.al "Multitime scale Markov decision processes," *IEEE Trans. Automatic Control* ,vol.48, pp. 976–987,2003

[13] Hyeong Soo Chang, Fard P,Marcus S.I ,et.al." A model for multi-time scaled sequential decision making processes," *In Proc.* 2002 *Conference on Decision and Control,* pp.3813 - 3818

[14] Qiying Hu and Jianyong Liu . *Theory of Markov decision process*, Xidian University Press, Xi'an, 2000 pp..

[15] Campo R A. "Probabilistic optimality in long-term energy sellings," *IEEE Trans. Power Systems*, vol.17, pp. 237-242, 2002.

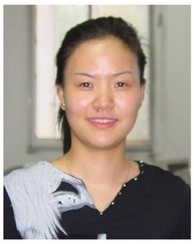
[16] Xiaohong Guan, Alva Svoboda and Chao-an Li. "Scheduling hydro power systems with restricted operating zones and discharge ramping constraints," *IEEE Trans. Power Systems,* vol. 14, pp. 126-131, 1999.

VIII. Biographies

Chengjun Zhu was born in Jiangsu province of China, on Mar 23, 1974. He received his BS degree in hydraulic structure engineering in Wuhan University in 1995 and MS degree in hydropower engiering in Wuhan University in 1998. Currently, He is a PhD student in College of hydropower and information engineering at Huazhong University of Science and Technology. His research interests include electricity market, hydropower portfolios management and bidding strategies of hydropower producers.

Jianzhong Zhou (SM'1994) was born in Wuhan in Hubei province. Now, he is a Professor and the head of college of hydropower and information engineering in Huazhong University of Science and Technology (HUST), Wuhan, China. His current research fields include hydropower generation planning, energy complex analysis of advanced theory and methods; Generation production process control and simulation; High-performance networks and information systems.

Junjie Yang was born in Hubei of China. He received his BS degree in physics in Huazhong Normal University in 1991 and MS degree in automation of electric power systems in Huazhong University of Science and Technology (HUST) in 1998. Currently, He is a PhD student in College of Hydroelectric and Information Engineering at HUST. His research interests include modern optimization theory and algorithm and its application in optimal operation of hydropower energy system.



Wei Wu was born in Zhengyan in Henan province of China, on May 1,1979. She received the BS degree in 2000 in mathematic in Henan normal University and MS degree in 2003 in probability theory and mathematic statistics in Huazhong University of Science and Technology (HUST). Currently, she is a PhD student in the college of hydropower and information engineering in HUST. Her main interests include electricity market and bidding strategies of hydropower producers.