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福建省电力系统分析和核电规划

FUJIAN ELECTRIC SYSTEM ANALYSIS AND NUCLEAR POWER PLANNING

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福建省电力系统分析和核电规划

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摘 要

为制定福建省初步的长期电力扩展规划和核电发展规划，开发了 WASP 软件包。采用 ENPEP（能源规划与评价）软件包中的两个模型（LDC & ELECTRIC）进行最优扩展规划。采用 LDC（负荷持续曲线）模型分析系统负荷情况。ELECTRIC（电力）模型用来优化电力系统。WASP-Ⅲ 可以在满足约束条件的情况下产生一个不超过 30 年的电力系统经济最优扩展方案。根据贴现费用大小来评价方案是否最优。基于不同扩展方案的成本比较，在系统扩展规划中运用概率模拟法分析发电成本、电力缺口以及系统可靠性。结果表明：在所有可用的技术与资源中，水电最为便宜。在将来的系统中，600 MW 的火电厂最具有竞争力。在研究期末（2020 年），大约二分之一的机组将由这类机组构成。当基荷上升到某一水平时，引入 600 MW 的核电厂（在 2005 年左右）对于系统来说是合理的。燃油机组将会降低系统的成本。

FUJIAN ELECTRIC SYSTEM ANALYSIS AND NUCLEAR POWER PLANNING

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ABSTRACT

The objective of the study is to conduct a long term electric expansion planning and nuclear power planning for Fujian Province. The Wien Automatic System Planning Package (WASP-III) is used to optimize the electric system. Probabilistic Simulation is one of the most favorite techniques for middle and long term generation and production cost planning of electric power system. The load duration curve is obtained by recording the load data of a time interval into a monotone non-increasing sense. Polynomial function is used to describe the load duration curve(LDC), and this LDC is prepared for probabilistic simulation in WASP-III. WASP-III is a dynamic optimizing module in the area of supply modelling. It could find out the economically optimal expansion plan for a power generating system over a period of up to thirty years, with the constraints given by the planners. The optimum is evaluated in terms of minimum discounted total costs. Generating costs, amount of energy not served and reliability of the system are analyzed in the system expansion planning by using the probabilistic simulation method. The following conclusions can be drawn from this study. Hydro electricity is the cheapest one of all available technologies and resources. After the large hydro station is committed at the end of 1995, more base load power plants are needed in the system. Coal-fired power plants with capacity of 600 MWe will be the most competitive power plants in the future of the system. At the end of the studying period, about half of the stalled capacity will be composed of these power plants. Nuclear power plants with capacity of 600 MWe are suitable for the system after the base load increases to a certain level. Oil combustion units will decrease the costs of the system.

1 APPROACH

• Objective and Scope of the Study

The objective of the study is to conduct a long term electric expansion planning(including nuclear power planning) for Fujian Province. The scope of the study is the isolated grid of Fujian.

• Analytical Tools

Two modules of ENPEP (ENergy and Power Evaluation Package) are used to conduct the optimal expansion planning:

- LDC (Load Duration Curves) module is used to analyze the system load.
- ELECTRIC (WASP-III) is used to optimize the electric system.

• Approach Applied

Probabilistic Simulation is one of the most favorite techniques for middle/long term generation and production cost planning of electric power system. The load duration curve is obtained by recording the load data of a time interval into a monotone non-increasing sense. Polynomial function is used to describe the load duration curve (LDC), and this LDC is prepared for probabilistic simulation in WASP-III module.

WASP-III is a dynamic optimizing module in the area of supply modelling.It could find out the economically optimal expansion plan for a power generating system over a period of up to thirty years, with the constraints given by the planners. The optimum is evaluated in terms of the minimum sum of total discounted costs. Generating costs, amount of energy not served and reliability of the system are analyzed in the system expansion planning, by using the probabilistic simulation method.

• Principal Results of the Study

Hydroelectric power is the cheapest one of all available technologies and resources. After the large hydro power station, Shuikou hydro power station, is committed in the system at the end of 1995, more base load power plants would needed in the system. Coal-fired power plants with the capacity of 600 MWe will be the most competitive power plants in the future of the system. At the end of the study period, about half of the installed capacity will be composed of this kind of units. Nuclear units with the capacity of 600 MWe are suitable for the system after the base load increases to a certain level. Oil-combustion units will decrease the costs of the system.

2 BASIC ASSUMPTIONS

2.1 Current and Historical Development of the System

- **History of System Development**

Established on the basis of formal Fujian Electric Power Administration in 1983, Fujian Electric Power Bureau as a large enterprise under the direct jurisdiction of Ministry of Electric Power and also as a functional sector of Fujian Provincial People's Government, is responsible for the planning and administration of electric power industry of the Province.

In 1992, the total installed capacity in Fujian Province's grid reached 3404 MWe, among which thermal power accounted for 1652 MWe and hydro power 1752 MWe, the power generation reached 16 TW·h, among which hydro electricity accounted for 7.9 TW·h, and thermal is 8.1 TW·h. In 1992, the total length of the 220-kV and up transmission lines has reached 2000 km.

The biggest thermal power plant is Huaneng-Fuzhou thermal power plant (2x350 MWe). The biggest hydro power station is Shuikou hydro power station (7x200 MWe)[1].

- **Capacity and Generation Broken down by Source**

The total[2] power generation reached 17.66 TW·h in 1992, among which hydropower accounted for 9.49 TW·h, the average annual growth rate was 9.7%, and thermal power accounted for 8.17 TW·h, the average annual growth rate was 13.4%. Most hydro power stations are run-of-river stations, and a few of them have regulating reservoirs. In general, the total hydro generation between March and June is 1.5 to 2.0 times as that between November and February each year.

- **Peak Load**

In 1992, the daily peak load in Fujian electric grid was 2350 MWe, the average annual growth rate from 1985 to 1992 was 13.6%, and the daily maximum generation was 46.31 GW·h. The average annual growth rate of daily maximum generation from 1985 to 1992 was 13.8%.

- **Transmission**

Now, in the Fujian grid, the 220-kV double-looping lines have been

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[1] Four units have gone to serviced in the utility.

[2] Not only means the isolate grid generation, but the whole province.

introduced into operation. The connection rate of the province's cities and counties to the grid reached 81% or over. In 1992, the total length of transmission lines in the grid above 110-kV reached 5700 km, among which 220 kV lines accounted for 2000 km, 110-kV lines 3700 km.

2.2 Projections of demand

The projections of electric energy demand been finished by the run of the LDC module. Five scenarios are projected as the demand forecasts of Fujian electric system. The middle scenario is selected as the base scenario. The projection results are shown as Fig.1, Fig.2 and Table 1 to Table 3.

Fig. 1 Load Forecast of Base Case

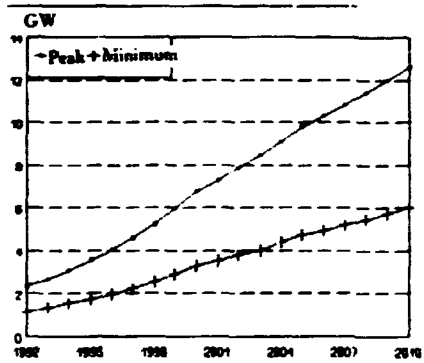
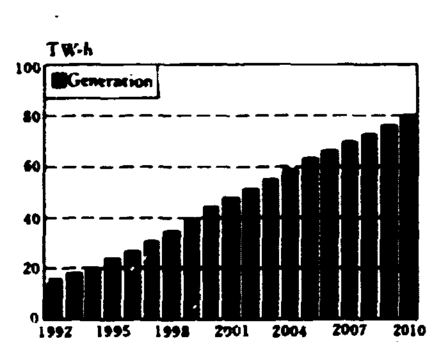


Fig. 2 Generation Forecast of Base Case



The projection is based on the following points:

- The generation demand of five scenarios are the outputs of DEMAND[3] module. The load factor of Fujian electric system was about 77.65% in 1992. The ratio of minimum load to peak load was about 0.65:1 in 1992. The high load factor and the ratio of minimum load to peak load will decrease over the planning period, with the increasing of the people living standard and the diversity of industry.

- The projection of load factor and the ratio of minimum load to peak load are based on the forecast of Fujian Electric Company.

- The period peak fraction and period generation fraction used in the study are also the results from Fujian Electric Company.

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[3]One of the ENPEP model.

Table 1 Projections of System Demand(Base Scenario)

YEAR	PEAK LOAD MWe	GROWTH RATE %	MINIMUM LOAD MWe	GROWTH RATE %	ENERGY GW·h	GROWTH RATE %	L.F. %
1992	2348.8	-	1181.1	-	15976.7	-	77.65
1993	2676.9	14.0	1346.1	14.0	18140.4	13.5	77.36
1994	3083.6	15.2	1550.6	15.2	20181	14.8	77.07
1995	3558.6	15.4	1729.4	11.5	23934	15.0	76.78
1996	4050.1	13.8	1968.3	13.8	27136	13.4	76.49
1997	4608.2	13.8	2239.5	13.8	30758	13.3	76.19
1998	5242.1	13.8	2547.6	13.8	34855.9	13.3	75.9
1999	5962.2	13.7	2897.5	13.7	39492.9	13.3	75.62
2000	6780.7	13.7	3295.3	13.7	44741.5	13.3	75.32
2001	7303	7.7	3525.6	7	48000.8	7.3	75.03
2002	7864.8	7.7	3796.8	7.7	51494	7.3	74.74
2003	8469.3	7.7	4008.7	7.7	55236.8	7.3	74.45
2004	9119.6	7.7	4402.6	7.7	59240	7.2	74.15
2005	9819.3	7.7	4740.4	7.7	63537.6	7.3	73.87
2006	10324.6	5.1	4932.2	4	66547.2	4.7	73.58
2007	10856.1	5.1	5186.1	5.1	69690.5	4.7	73.28
2008	11415.2	5.2	5453.2	5.2	72989.8	4.7	72.99
2009	12003.4	5.2	5734.2	5.2	76460.1	4.8	72.72
2010	12622.1	5.2	6029.8	5.2	80070	4.7	72.42

Table 2 Projections of System Demand(High Scenario)

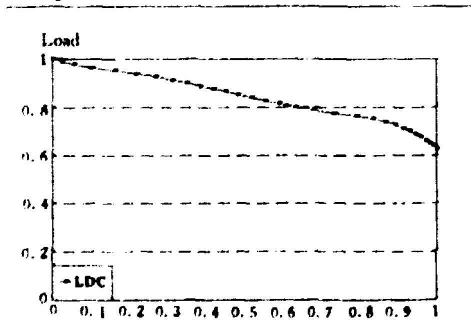
YEAR	PEAK LOAD MWe	GRO. RATE %	MIN. LOAD MWe	GRO. RATE %	GEN. GW·h	GRO. RATE %	L.F. %
1992	2348.8	-	1181.1	-	15976.7	-	77.65
1993	2690.3	14.5	1352.8	14.5	18231.2	14.1	77.36
1995	3613.8	16	1756.2	12.1	24305	15.6	76.78
2000	7130.6	14.5	3465.3	14.5	47050.3	14.1	75.32
2005	10884.2	8.8	5254.5	8.8	70428.2	8.4	73.87
2010	14649.3	6.1	6998.2	6.1	92929.8	5.7	72.42

Table 3 Projections of System Demand(Low Scenario)

YEAR	PEAK LOAD MWe	GRO. RATE %	MIN. LOAD MWe	GRO. RATE %	GEN. GW·h	GRO. RATE %	L.F %
1992	2348.8	-	1181.1	-	15976.7	-	77.65
1993	2613.5	11.3	1314.2	11.3	17710.7	10.9	77.36
1995	3307.1	12.6	1607.2	8.8	22242.5	12.1	76.78
2000	6203.1	13.4	3014.6	13.4	40930.3	12.9	75.32
2005	8609.4	6.8	4156.3	6.8	55708.7	6.4	73.87
2010	10966.1	5	5238.7	5	69564.9	4.5	72.42

Fig. 3 is a load duration curve in August, 1994. It is obviously that the LDC has a high load factor and a high ratio of minimum load to peak load. As mentioned before, Fujian is lacking in electricity, and there is suppression of peak demand. This situation will keep in a relative long period. This is why the high load factor and high ratio of minimum load to peak load.

Fig. 3 Load Duration Curve (August, 1994)



2.3 Existing and Firmly Committed Power Generating Plants

- **Thermal power plants**

There are seven main thermal power plants in Fujian electric grid. Six of them are coal-fired power plants and one is oil-fired.

Huaneng Fuzhou coal-fired power plant(2x350MWe) is the largest thermal plant and fueled by imported coal. The second largest thermal units are with a capacity of 100 MWe. Over 350 MWe installed capacity are composed of small units(less than 25 MWe). Most of these units are used as base load. Contrarily, Huaneng-Fuzhou power plant, the high efficiency power plant, is usually, but, used as peak load. This is due to the large proportion of hydro power plants, the high price of imported coal and also its load following capability is better than those of other thermal plants. The technical and economic data of some main thermal power plants are shown in Table 4.

There is no existing units fueled by abroad coal. In order to conduct sensitivity studies,the fuel cost of the units fueled by the coal imported from North China are assigned to foreign cost category. We also grouped the maintenance classes for the small units, in order to reduce the running time of the code.

- **Hydro Stations**

There are 16 main hydro stations in Fujan, with a total capacity of 1161 MWe. The regulating capability and some characteristics are shown in Table 5.

There are only a small proportion of these hydro stations having long time regulating capability in the system. These hydro stations have 333 MWe installed capacity. Most of the existing hydro stations have only short regulating capability. But in dry seasons,almost all of these hydro stations are closed at night and operated in the daytime for peaking demand. The mini hydro stations with a total capacity of 770 MWe are connected with the grid. These mini hydro stations have relatively regulating capability. About 300 MWe mini hydro stations will be committed and interconnected with the grid in the next 20 years.

- **Evolution of Fixed System**

A total capacity of 2200 MWe power plants are under construction now. They will be committed in four years. A relatively large hydro power station with 1400 MWe (7x200 MWe) will be separately put into operation in 1993(400 MWe), 1994(600 MWe) and 1995(400 MWe).In order to more accurately simulate the system, we put this station into operation as three power stations in different years and the retirements are assumed.

Table 4 Technical and Economic Data of thermal power plants

NAME	Units	MINIMUM LOAD MWe	CAPACITY MWe	HEAT RATES $/KW*h BASE LOAD	HEAT RATES $/KW*h AVGE INCR	FUEL COST CENTS/MBTU	FUEL TYPE	FAST SPINNING RESERVE %	FORCED OUTAGE %	SCHEDULE MAINTANANCE d	MAINTANANCE CLASS MWe	O&M COST (FIXED) $/KW MONTH	O&M COST (VARIABLE) $/MW*h
1350	2	175	350	9698	9447	180	coal	29	13 2	52	350	0.54	0.61
1006	15	6	6	17347	17347	90	coal	0	11.5	43	12	0.47	0.71
1025	2	20	25	16093	13460	90	coal	1	12	47	25	0.58	0.66
1050	2	25	25	13794	13794	90	coal	0	12	48	25	0.68	0.77
1100	3	70	100	12373	10701	90	coal	0	12.5	49	100	0.68	0.77
1102	2	33	100	12456	10910	90	coal	0	12.5	50	100	0.84	0.95
1012	8	10	12	16469	12958	90	coal	0	10.8	43	12	1.9	2.33
1011	2	10	12	15508	12456	90	coal	1	11.5	46	12	0.91	1.39
1003	14	3	3	16720	16720	90	coal	0	11.5	39	12	1.42	3.23
OIL	3	33	33	12415	12415	240	oil	0	12.5	35	12	0.25	1.25
1300	0	150	300	9698	9447	180	coal	29	13.2	50	350	0.65	0.74

Table 5 Existing and Firmly Committed Hydro Stations

Hydro	On-line	Capacity MWe	Generation TW·h	Regulating Capability	Maintenance Days/a	L.F. %
GUTIAN-I	1960	62	0.347	yearly	47	63.89
CHITAN	1972	100	0.5	a.yearly	76	57.08
ANSHA	1972	115	0.62	seasonal	88	61.54
SHANMEI	1972	30	0.11	a.yearly	23	41.86
GUTIAN-II	1972	130	0.447	daily	99	39.25
GUTIAN-III	1972	33	0.117	daily	25	40.47
GUTIAN-IV	1972	34	0.124	daily	26	41.63
HUAAN	1972	60	0.393	daily	46	74.77
NANER	1972	25	0.088	daily	19	40.18
SHAXIKOU	1990	300	0.96	daily	230	36.53
FANCU	198[illegible]	36	0.12	daily	27	38.05
SHUIKOU	93,94,95	1400	4.95	seasonal	108	40.36
LIANGQIAN	1990	30	0.123	daily	23	46.80
SHUIDONG	93..94	80	0.28	seasonal	61	39.95
WANAN	94..95	45	0.136	a.yearly	34	34.50
MOWU	95..96	30	0.132	daily	23	50.23
NANYI	1993	25	0.068	a.yearly	19	31.05
LONGMENTAN	1992	26	0.1	a.yearly	20	43.91

There are two units with total capacity of 200 MWe will be committed in 1994 and 1995, and two units with 600 MWe will be committed in 1995 and 1996. The descriptions of retirements of the thermal power plants are shown in Table 6.

There is no retirement of hydro stations over the planning periods.

The evolution of existing and firmly committed system is shown in Table 7.

2.4 Candidates for Expansion

• Selection of the Candidates

There are four kinds of thermal power plants were selected as the candidates for the expansion: they are 600 MWe ,350 MWe and 300 MWe coal-fired power units and 600 MWe nuclear units. All of the thermal candidates are assumed to be domestically manufactured and constructed, and based on fuel to be imported from

Table 6 Retirements of thermal power plants

YEAR	L006	L025	L050	L102	L012	L011	L003	I300
1994				1				
1995	-1			1				1
1996	-1							1
1997	-1						-1	
1998	-1						-1	
1999	-1						-1	
2000	-1						-1	
2001	-1						-1	
2002	-1						-1	
2003	-1						-1	
2004	-1				-1	-1	-1	
2005	-1				-1	-1	-2	
2006	-1				-1		-2	
2007	-1				-1		-2	
2008	-1		-1		-1			
2009	-1	-1	-1		-1			
2010		-1			-1			

North China or abroad. This selection is mainly based on the existing planning for Fujian electric system expansion[4]. The availability of domestic technology and resource is the main reason why the candidates have been selected by the Fujian analysts and decision makers. Although the local coal production will reach 12 million tones per year at the end of this century, the small coal-fired power plants with low efficiency and fueled by local coal would not considered as candidates any more.

Thirty-eight hydro projects are considered as expansion candidates. These projects are planned by Fujian Electric Company and the local government. The fixed O&M cost of these hydro stations is assumed 0.3 $/kW·month. The main characteristics of these projects are many small projects and poor regulating capability. The generation of these projects in dry seasons is only half of the value in the wet seasons. The same proportion is assumed for the distribution of hydro generation from dry hydro condition to wet hydro condition.

[4]Actually, this does not seem to be a reasonable assumption for the system in the further, especially that there is no thermal peaking plant were included in the candidates.

Table 7 The Evolution of the Existing and Firmly Committed System

	HYDRO(MWe)		THERMAL(MWe)				TOTAL (MWe)
YEAR	LONG	SHORT	COAL	COAL	OIL	Nuclear	
1992	333	1419	852	700	99	0	3403
1993	573	1452	852	700	99	0	3676
1994	1248	1458	952	700	99	0	4484
1995	1969	1578	1046	1000	99	0	5692
1996	2004	1631	1040	1300	99	0	6074
1997	2004	1651	1031	1300	99	0	6085
1998	2004	1671	1022	1300	99	0	6096
1999	2004	1691	1013	1300	99	0	6107
2000	2004	1711	1004	1300	99	0	6118
2001	2004	1721	995	1300	99	0	6119
2002	2004	1731	986	1300	99	0	6120
2003	2004	1741	977	1300	99	0	6121
2004	2004	1751	944	1300	99	0	6098
2005	2004	1761	908	1300	99	0	6072
2006	2004	1771	884	1300	99	0	6058
2007	2004	1781	860	1300	99	0	6044
2008	2004	1791	817	1300	99	0	6011
2009	2004	1801	749	1300	99	0	5953
2010	2004	1811	712	1300	99	0	5926

2.5 Fuel Costs

The production costs of local coal are much lower than that of abroad,but the transportation fees are expensive and the total demands of this kind of coal are much larger than the total supplies in South China. So, the coal price is near the international price. The current coal price in Fujian is about 40 $/t. The imported coal price is determined by the market. This price is considered as the fuel cost in the model.

It is almost impossible to obtain variable O&M cost of power plants in China now. Fortunately,a rough total O&M cost is available in Fujian. So, the following method is chosen to determine the fixed and variable O&M costs:

Fixed O&M.cost(kW/a) =Total O&M cost(kW/a) x Capacity Factor(fraction)
Variable O&M Cost(kW/a)=Total O&M cost(kW/a) x (1-Capacity Factor)/8760

The O&M cost of the existing 350 MWe units is considered as the reference O&M cost of the candidates. The 350 MWe units were imported from Japan.Considering the difference between imported equipments and domestic equipments and the effect of different ca;⌐city,a small adjustment of the O&M cost of capacity was made.

The O&M cost of nuclear power plants is difficult to obtain in China now. The same proportion of nuclear O&M cost to coal-fired O&M cost is kept from the data of USA. The variable O&M cost of nuclear power plant is about one third of that of coal-fired power plants. The fixed O&M costs of nuclear is the same level of the coal-fired plant.

The O&M costs of the hydro power stations were assumed as two cents(RMB)/kW•h in 1992. This is the official data. It was transformed to fixed O&M cost in the model.

2.6 Investment Cost of the Candidates

The detailed data of the thermal candidates are shown in Table 8, and that of hydro candidates in Table 9. The interest rate is 8% per year. Lifetime of hydro station is 40 years.

3 REFERENCE CASE (Base Case)

- **Criteria for Generating Configuration Alternatives**

The basic assumptions to generating configurations is the available dates of hydro projects and their reserve margins. There is no limitation of thermal alternatives after 1996, except nuclear power plants. Considering the construction time and the policy of the government,we constrain nuclear power plants to two units and the earliest commission date is the year of 2005.

- **Minimum and Maximum Reserve Margins**

The reserve margin (nominal) of the system was 44.8%in 1992. The real reserve margin during critical period[5](Nov.) is 12%,due to the largely decreasing of capacity of hydro power station in this period.

The reserve margin range used in the model is from 20% to 40% after 1996,and from 10% to 50% before this year. The sensitivity studies have been conducted for different reserve margins. The results show that 20% to 40% reserve margin range is reasonable for the selection of the system configurations.

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[5] Means the period which the difference between the available capacity and the peak lo.d is the minimum.

Table 8 Thermal candidates

NAME		C600	C350	C300	N600
MINIMUM LOAD (MWe)		400	200	200	500
CAPACITY (MWe)		600	350	300	600
HEAT RATES	BASE LOAD	10241	10575	10868	10889
(kJ/kW • h)	AVGE INCR[6]	9238	9447	9489	10241
FUEL COSTS	DOMESTIC	0	0	0	202.5
CENTS/10E6 kJ	FOREIGN	180	180	180	0
FUEL TYPE		coal	coal	coal	nuclear
FAST SPINNING RESERVE %		20	20	20	7
FORCED OUTAGE %		14.5	14	13.5	15
SCHEDULE MAINTENANCE DAYS		55	54	52	55
MAINTENANCE CLASS (MWe)		600	300	300	600
O&M (FIXED)$/KW month		0.6	0.62	0.65	0.7
O&M (VARIABLE)$/MW • h		0.68	0.7	0.74	0.2

- **Criteria Used for Loading Order Calculation**

The spinning reserve of the system should meet the load demand when the largest unit in the system occurs forced outage. Considering the effect of the scale of the system,we decrease the spinning reserve by 1.5% of it's peak load. So, the formula of calculating the spinning reserve is as the follow:

Spinning Reserve = 1.0 x Capacity of the Largest Unit - 0.015 x Peak Capacity

- **Loading Order for Thermal Plants**

Economic loading order is assumed for the thermal units under the constraint of spinning reserve. So, before the retirement of the thermal units fueled by local coal, the system loads these units first, and then the units fueled by imported coal. After the nuclear plants are committed, the base blocks will be loaded as single peaking blocks. The units with capacity of 600 MWe,fueled by imported coal will be loaded after the existing 350 MWe units because of the heat rate and O&M cost.

- **Economic Parameters Selected**

The discount rate was assumed to be 8% per year (this number is used in most economic studies in China now and recommended by the government) and

[6] Average incremental heat rate (between a smaller load level and a larger load level)

Table 9 Hydro Candidates for Variable Expansion

Hydro Stations	On-Line Date	Capa. (MWe)	Gener. (TW·h/a)	Constr-uction (a)	Capital Cost($/kW)	Regu-lating Capa-bility
QINSHAN	1995-2000	70	0.145	5	827.586207	yearly
ZHOUNING	1995-2000	250	0.658	6	862.068966	yearly
MIANHUATAN	1995-2000	600	1.5[illegible]	6	913.793103	a.year
MINDONG	1995-2000	80	0.[illegible]	3	775.862069	daily
BANZHUXI	1995-2000	38	0.123	4	810.344828	daily
XIAYANG	1995-2000	39	0.183	4	775.862069	daily
KONGTOU	1995-2000	39	0.165	4	724.137931	daily
HONGKOU	1995-2000	200	0.47	6	689.655172	a.year
DAMUXI	2000-2005	58	0.15	5	689.655172	yearly
SHANGPEI	2000-2005	111	0.316	5	741.37931	daily
JIEMIAN	2000-2005	400	0.598	6	715.517241	yearly
BAINAI	2005-2010	50	0.19	4	896.551724	season
HUOKOU	2005-2010	150	0.3	6	689.655172	yearly
ANFENGQIAO	2000-2005	180	0.625	5	698.275862	daily
DAYAN	2005-2010	30	0.113	4	689.655172	daily
BANMIAN	2005-2010	35.2	0.144	4	741.37931	daily
JINGSHAN	1995-2000	30	0.126	4	862.068966	daily
TAIJIANG	2010-2015	25	0.104	4	724.137931	daily
ZHUZHOU	2010-2015	44	0.156	4	741.37931	daily
GONGCHUAN	2010-2015	32	0.128	4	889.655172	daily
ZHAOKOU	2010-2015	45	0.217	4	689.655172	daily
YANGKOU	2010-2015	39	0.181	4	741.37931	daily
GAOTANG	2010-2015	25	0.11	4	827.586207	daily
HUANTANG	2010-2015	25	0.105	4	775.862069	daily
YONGKOU	2010-2015	35.2	0.167	4	779.310345	daily
WENTANG	2010-2015	25.2	0.104	4	779.310345	daily
DAZHANGXI	2010-2015	291	0.948	7	896.551724	a.year

January 1st, 1992 was adopted as the base date for all discounting calculations. All the costs were expressed in December 31st, 1990 Chinese RMB, which means the constant monetary unit was used. The discount rate for operation cost and fuel cost are also 8% per year. Escalation was not considered in the base case.

The cost of Energy-Not-Serve(ENS) is assumed as 1$/kW·h. Actually it is difficult to get the practical value of ENS in China now,because there is no such institutional research. But the analysts and decision makers really concern the result of energy shortage. Consequently, some estimation can be got from some experts. It is estimated that the added value of 1 kW·h in industry sector in South China is more than 1$. This is the average ENS cost but no one knows the marginal ENS cost. Only 1$/kW·h is chosen as the first coefficient of the formula to calculate the ENS cost.

- **Constraints**

The existing system has a low reliability due to the energy shortage and the peak plants shortage. So, there is no LOLP constraint during first 12 years in the study period. After 2005, 0.5% LOLP constraint is imposed to the system.

30 is selected as the number of the Fourier coefficient to simulate the load duration curve of the system.

4 ANALYSIS OF OPTIMAL SOLUTION RESULTS

- **Optimal Solution**

Table 10 is the result of the optimal solution. The result shows what the most competitive candidates is hydro projects, especially the short regulating hydro stations. Before 2005, the hydro projects with long regulating capability are suppressed by the system. This is mainly due to the high capital costs and low capacity factors and the commission of the largest hydro stations in 1996. This hydro station will cause energy spillage in 1996, 1997, and 1998. So, the peak load can be well met before 2005. Because the system need more economic base load units and the nuclear power plants are available in 2005,the nuclear power plant is admitted by the system.

During the planning period, the coal-fired power plants with capacity of 600 MWe are the main units committed in the system. At the end of the study period, 600 MWe coal-fired power plants will take about 40% of the total install capacity.

Nuclear power plants with 600 MWe are competitive with other candidates. Due to the government's policy, only two units of nuclear are considered in the system.

The reserve margin of the system will decrease due to the proportion of thermal power plants.

Table 10 Optimal Solution

	HYDRO		THERMAL				TOTAL	SYSTEM	
	CAPACITY							RES.	LOLP.
YEAR	LONG	SHORT	COAL	COAL	OIL	Nuclear		%	%
1992	333	1419	852	700	99	-	3403	44.9	0.222
1993	573	1452	852	700	99	-	3676	37.3	1.243
1995	1969	1578	1046	1000	99	-	5692	60	0.006
2000	3124	1967	1004	3700	99	-	9894	45.9	0.033
2005	3524	2227	908	6100	99	600	13458	37.1	0.208
2006	3524	2380	884	6100	99	1200	14187	37.4	0.171
2010	3782	2445	712	8500	99	1200	16748	32.7	0.396

- **Financial Analysis**

The investment costs will increase to the top from 2000 to 2002. After this period,the investment costs of the thermal will take a large share of the total capital costs.

The operation costs of the system will shift from local coal-fired power plants to the imported coal-fired power plants during the evolution of the system. At the end of the study period, the coal-fired power plants fueled by imported coal will take the predominant position of the total operation coats. The total cash flow which includes the operation costs and capital costs of the system will reach the highest point near the end of the study period. Around 2000, there is also a peak of the total costs,due to the high investment cost of hydro and the high investment costs of nuclear.

Fig. 4 Total Cost Cash Folw

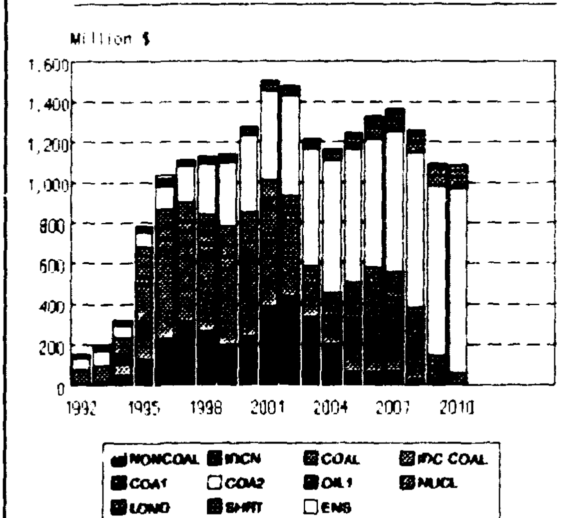


Fig.4 shows the total cost cash flow (total capital cash flow + total operation costs[7])

[7]Including the costs of energy not served.

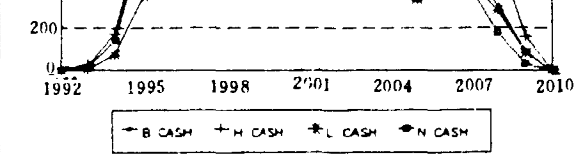
In order to judge the financial situation of the electric company,we roughly analyze the net cash flow of the company. This analysis does not consider the debt of the company at present and the firmly committed power plants either. The electric price is assumed as three cents per kW·h and does not consider the escalation of the electric price. The net cash flow of the company will keep near equilibrium at the middle stage of the study period. At the first two or three years,there is a relatively large surplus in the net cash flow. This situation will occur at the end of the study period. This is a reasonable result. But around 2002,the net cash flow is negative. This should be emphasized by the company and the government.

5 SENSITIVITY STUDY OF DIFFERENT CONSTRAINTS TO CANDIDATES

About six different sensitivity studies have been conducted. They can be divided into two categories, one is about the different load forecast scenarios, the other is about the different constraints or different key parameters but based on the same load forecast(base case load forecast).

Based on the forecast mentioned before, the optimal expansion planning for different scenarios are obtained. The different capital cash flow are shown in Fig.5. The installed capacity and corresponding system reserve margins are shown in Table 11 and Table 12.

Fig. 5 Capital Cash Flow of Different Load Scenarios



- **Acceleration of Nuclear**

There are only two nuclear units considered by the government in the planning period. The base case shows that the nuclear power plants are competitive with other candidates. Then six nuclear units are selected as the candidates,but the construction of commission year is imposed to these units. The six units are added to the system once they are available.

Table 11 Installed Capacity of High Scenario

	HYDRO		THERMAL FUEL TYPE				TOTAL CAPA-CITY	SYSTEM RESER-VE		ENS GW*h		
	CAPACITY (MWe)								LOLP.	HYDR.CON		
YEAR	LONG	SHORT	COAL	COAL	OIL	Nuclear	MWe	%	%	1	2	3
1992	333	1419	852	700	99	0	3403	44.9	0.222	2	1	0
1993	573	1452	852	700	99	0	3676	40.7	0.494	5	3	1
1995	1969	1578	1046	1000	99	0	5692	72.1	0	0	0	0
2000	2004	1967	1004	3400	99	0	8474	36.6	0.39	13	3	1
2005	3124	2259	908	4950	99	600	11940	38.7	0.148	6	1	0
2006	3124	2269	884	4950	99	1200	12526	38.6	0.163	7	1	0
2010	3782	2455	712	6750	99	1200	14998	36.8	0.154	7	1	0

Table 12 Installed Capacity of Low Scenario

	CAPACITY (MWe)							SYSTEM		ENS		
	HYDRO		THERMAL				TOTAL	RESER-VE	LOLP	HYDRO CONDITION		
YEAR	LONG	SHORT	COAL	COAL	OIL	Nuclear	MWe	%	%	1	2	3
1992	333	1419	852	700	99	0	3403	44.9	0.222	2	1	0
1993	573	1452	852	700	99	0	3676	40.7	0.494	5	3	1
1995	1969	1578	1046	1000	99	0	5692	72.1	0	0	0	0
2000	2004	1967	1004	3400	99	0	8474	36.6	0.39	13	3	1
2005	3124	2259	908	4950	99	600	11940	38.7	0.148	6	1	0
2010	3782	2455	712	6750	99	1200	14998	36.8	0.154	7	1	0

The hydr. con. which in the last column in the table 11 means the hydro conditions. And the number 1, 2, 3 means that: 1-- dry condition, 2-- normal condition, 3-- wet condition.

• Environmental Protection

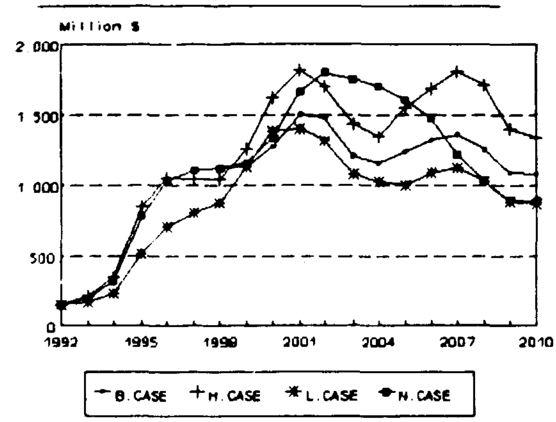
We increase the capital costs of coal-fired power plants 15%,as the FGD investment costs.There is a small different change in the system. So,only the objective function of the optimal solution is compared with the base case

• Discount Rate

In the base case,8% per year is selected. When we adopt 10% per year,the optimal solution is changed. The nuclear power plants is removed from the expansion planning. Because of high capital costs(twice as coal-fired power plants),it is very sensitive to the discount rate. The two nuclear units are replaced by 600 MWe coal-fired power plants. This can be explained exactly from the screening curves. The cash flow of this case has not been discussed,because the different discount rate is the different base for comparison.

The total cash flow of the different constraints to candidates are shown in Fig.6.

Fig. 6 Different Cases Total Cash Flow



6 CONCLUSIONS AND RECOMMENDATIONS

From the results of optimal solution and sensitivity study,we can obtain following conclusions and recommendations:

• The hydro projects in Fujian should be given some priorities due to the lower capital costs and cheaper O&M costs than that of thermal plants. The main constraint is the construction time if the fund is available.

It is not only the installed capacity and the capital costs of the hydro projects, but also the regulating ability and the dynamic situation of the system that should be taken into consideration. The reasonable schedule of constructing the hydro projects should be arranged, consideration with the situation of the system. Acceleration of hydro is a clever choice, in view of the system costs.

Before the commission of the large hydro station at the end of 1995,there will be some peak and shortage in Fujian. So,it is necessary for the local government to accelerate the construction of the large hydro station and the other two thermal units, in order to reduce the loss caused by the electricity shortage.

After the commission of the large hydro station and the two thermal units,the system will keep a good reliability and the peak demand will be met.

• The coal-fired power plants with 600 MWe capacity will be the main type of power plants in the next two decades in the system. This is mainly due to the large hydro proportion of the system and a relatively poor regulating capability of the hydro system. So,the system needs the base load thermal units in the dry seasons,and needs peak load thermal units in the wet seasons. It is suitable for the system to be expanded with the large scale of the power plants,because of the effect of scale and the high efficiency.

The Fujian government is planning to construct two thermal units of 350 MWe capacity. This decision should be careful, because, from the economic point of view, it is more suitable to construct 600 MWe coal-fired plants in the near future, in stead of 350 MWe coal-fired power plants.

• As the results of the optimal solution have shown us, there will be a large proportion of coal-fired power plants in the system. As mentioned before, it is not possible for the province to construct coal-fired power plants which are fueled by local coal. So, how to realized the transportation of the much amount of fuel coal and where, of course, the abroad coal could be get are both the crucial points to achieve the optimal expansion planning.

• Environmental pollution will be another problem which should be paid more attention by the local government, for the large amount of coal consumption. There is no any desulfurlization device installed for the coal-fired power plants now. The damages of SO_X and NO_X emissions have been found. So, it is necessary for us to consider the capital costs and operation costs of environmental protection devices in the future. This will also increase the costs of coal-fired power plants.

• It is possible for the nuclear power plants to become another option for the system expansion, especially after the base load reaches a relative level. According to characteristics of nuclear power plants, the nuclear power plants are competitive with the coal-fired power plants, nuclear power plants should be given enough emphasis. Actually, more nuclear power plants will be suitable for the system.

- Financial process is another tough problem for the system expansion. In order to solve this problem, the reform of electric price will be inevitable. According to the rough financial analysis in the sensitivity study, 3 cents/kW·h is not a reasonable price for the self development of Fujian Electric Company actively. It is impossible for the government to input a relatively large amount of money into the system expansion. A wide range of financial channels should be opened to the electric sector, such as independent foreigner investments.

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