Miscellaneous Industries: Case 3
Reduction of Line Loss in Low-Voltage Power Distribution Networks

Introduction

In 1991, total electricity generation in China was 677.6 twh, while electricity supplied to users was 619.5 twh. The difference between the two figures is due to loss in the transmission and distribution network. Although some line loss is expected, losses in the Chinese transmission and distribution network are well above international standards.

Losses of eight percent occur between the generator and the high voltage transformer, while losses of nine percent occur in the high voltage network. The remainder of losses averaging between 8 and 15 percent are registered in the low-voltage distribution network. The variability in terms of low-voltage network performance is due to a number of factors including; outmoded equipment, high demand pressures leading to equipment overload, and the lack of reactive power compensation on Chinese appliances. Surveys in Hangzhou and Ningbo cities in Zhejiang Province indicate that the loss in the low-voltage network is attributed to:

Table 1. Transmission Loss in Low-Voltage Power Network

Item	Power Loss
Low-voltage transformer	3 %
Overhead line (or cable)	8 %
Reactive power	4 %
Total	15 %

The principal technical solutions to address low-voltage power network loss include:

- replacement of out-of-dated transformers,
- replacement of feeder lines or cable, and
- installation of reactive power compensation.

In addition to losses on the supply side, electricity demand has been increasing dramatically given rapid industrialization that includes both quantitative and qualitative changes in production technology. Domestic power demand also has been rising at a rapid rate. Over the last ten years, the per household power load has doubled from 0.5 to 1.0 kw. The corresponding electricity consumption has increased from 10-20 kwh per month to 60-80 kwh per month and in some cases higher levels still. Relative prosperity and a significant rise in household appliance usage have contributed to this change. Along with technical improvements to increase generating capacity and operational efficiencies, efforts to improve demand management will be necessary as well.

From a technical perspective, line loss reduction offers the potential to forego a portion of the expansion in generating capacity that will be required to meet rapidly growing electricity demand. A reduction in line loss from 15 percent to 8.9-11.5 percent results in an average electricity savings of 3.5-6.1 percent. A five percent operational savings could result in an annual reduction in electricity consumption of 5.3 twh

countrywide. Accounting for distribution losses, those savings are equivalent to annual savings of 6.4 twh in power generation and 2.49 million tce in coal consumption. Translated to generating capacity, 6.4 twh is equivalent to added generating capacity of 1.28 gw, the capital cost of which would be 6.4 billion yuan for the power plant and high voltage transmission network.

The Hangzhou and Ningbo Municipal Power Supply Bureaus are used for this case study. These two power supply bureaus are the largest in Zhejiang Province and the most efficient systems from a technical perspective. Zhejiang Province is one of the most rapidly growing provinces in the country and power generating capacity is of critical importance.

Because of new construction and extensive renovation efforts over the past ten years, these two systems are well above national standards. Still, these two systems have 25 percent of their low-voltage system in single phase line, 70 percent of branch lines in sub-station areas have not been renovated, and 80 percent of the low-voltage system does not have reactive power balanced at the site.

Technology Assessment

Current Technology: For comparison purposes, the without project case is for a standard 315 kva capacity system. The transformer is inefficient, the line cross-section is small and the power factor is low. Losses occur at the transformer (3 percent), along the line (8 percent), and in terms of reactive power flow (4 percent). The transformer's capacity is 315 kva with electricity sales of 401.6 mwh (based on 2500 annual operating hours); electricity supply is 472.5 mwh reflecting a 70.9 mwh loss in transmission.

Proposed Technology: The with project case involves replacement of the transformer and trunk lines - both overhead line and cable are considered. Reactive power compensation also is added with two alternatives examined. In case 1, the capacitors are installed at the end user's side of the line; in case 2, the capacitors are installed along the line just below the transformer. After replacement, losses at the transformer are reduced to 1.9 percent and the line loss rate to 6 percent. Reactive power losses are reduced to 1 and 3.6 percent, respectively, in Cases 1 and 2. Total losses are reduced to 8.9 in Case 1 and to 11.5 percent in Case 2. Annual power sales reach 430.5 mwh and 418.2 mwh resulting in a reduction of line loss of 28.8 and 16.5 mwh in Cases 1 and 2 as indicated in Table 2. This reduced line loss translates into 39.4 and 23.5 mwh in power generation.

Table 2. Major Production Indicators With and Without Project

	With Project		Without	Incremental	
Items	Case (1)	Case (2)	Project	Case (1)	Case (2)
1. System capacity (kva)	315.00	315.00	315.00	0.00	0.00
2. Power factor (%)	95.00	95.00	75.00	20.00	20.00
3. Line loss rate (%)	8.90	11.50	15.00	-6.10	-3.50
a. Transformer	1.90	1.90	3.00	-1.10	-1.10
b. Power factor	1.00	3.60	4.00	-3.00	-0.40
c. Conductor	6.00	6.00	8.00	-2.00	-2.00
4. Annual power sales (mwh)	430.45	418.16	401.63	28.82	16.54
5. Actual power supply (mwh)	472.50	472.50	472.50	0.00	0.00
6. Line losses (mwh)	42.05	54.34	70.88	-28.82	-16.54
7. Electricity price (yuan/mwh)	280.00	280.00	280.00	0.00	0.00
8. Company sales income (1000 yuan)	120.53	117.09	112.46	8.07	4.63
9. Ability of power supply (mwh)	748.13	748.13	590.63	157.50	157.50
10. Available capacity (kw)	299.25	299.25	236.25	63.00	63.00

Financial Analysis

Investment with the project is indicated in Table 3. With overhead lines, investment costs amount to 81,600 RMB yuan in case 1 with capacitors at the user's end and 67,200 yuan in case 2 with capacitor's at the back side of the transformer. With cable, per unit line costs increase fivefold and installation costs nearly triple. Overall, investment costs increase to 196,800 yuan in case 1 and 182,400 yuan in case 2 using cable.

Table 3. Investment With Project for Overhead and Cable Lines (1,000 yuan)

Items	Case 1	Case 2
1. Transformer (l set)	20.00	20.00
2. Capacitor (100 kva)	24.00	12.00
3. Conductor		
a. Overhead	24.00	24.00
b. Cable	120.00	120.00
4. Installation		
a. Overhead	13.60	11.20
b. Cable	32.80	30.40
5. Total		
a. Overhead	81.60	67.20
b. Cable	196.80	182.40

*. Conductor length & price

	(m)	(yuan/m)
a. Overhead	600.00	40.00
b. Cable	600.00	200.00

Because the project involves electricity savings in a tight supply situation, the project offers the option to forego construction of new generating capacity. With the project, reduced line loss leads to increased power supply capacity of 8.27 - 14.41 kw and to increased network transmission capacity of 63 kva. Table 4 shows investment and generation costs necessary to provide comparable system capacity. Investment costs amount to 198,000 yuan in Case 1 and to 167,340 yuan in Case 2; variable generating costs are estimated at 70 yuan per mwh.

Table 4. Investment Without Project (1,000 yuan)

Items	Case 1	Case 2
1. Added power supply capacity	14.41	8.27
2. Added network capacity (kva)	63.00	63.00
3. Power investment (yuan/kw)	5000.00	5000.00
a. Power plant	3000.00	3000.00
b. Transmission	850.00	850.00
c. Distribution	1150.00	1150.00
4. Total Investment (1000 yuan)	198.06	167.34
5. Generation costs (yuan/mwh)	70.00	70.00

As indicated earlier, annual electricity savings amount to 28.8 mwh under case 1 and to 16.5 mwh under case 2. Valuing power at the retail price of 280 yuan per mwh, leads to annual cost avoidance of 8,070 yuan in case 1 and 4,631 yuan in case 2. Table 5 shows incremental cost comparisons with and without the project using overhead lines. With initial investments of 81,600 in case 1 and 67,200 in case 2, the projects show

negative net present values and rates of return of -0.46 and -6.58 percent. Per unit costs amount to 531 yuan in case 1 and 763 yuan in case 2. Those costs are 251 and 483 yuan higher than the current retail price.

Table 5. Incremental Costs With and Without Project Using Overhead Lines (1,000 yuan)

	With Project		Without Project		Incremental	
Year	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	81.60	67.20			-81.60	-67.20
2			8.86	5.23	8.86	5.23
3			8.86	5.23	8.86	5.23
4			8.86	5.23	8.86	5.23
5			8.86	5.23	8.86	5.23
6			8.86	5.23	8.86	5.23
7			8.86	5.23	8.86	5.23
8			8.86	5.23	8.86	5.23
9			8.86	5.23	8.86	5.23
10			8.86	5.23	8.86	5.23
Total	81.60	67.20	79.73	47.09	-1.87	-20.11
PV	72.86	60.00	42.14	24.89	-30.71	-35.11
Irr					-0.46%	-6.58%
Unit cost* (yuan/mwh)	531.34	762.63	280.00	280.00	-251.34	-482.63

*Electricity savings/mwh cost

Table 6 shows incremental cost comparisons using cable lines. Because of the much higher investment costs for cable lines versus overhead lines, the returns are still less favorable in these cases. Rates of return are -15.06 and -20.96 percent. Per unit costs rise to 1281 and 2070 yuan per mwh making the project completely unfeasible.

Table 6. Incremental Costs With and Without Project Using Cable Lines (1,000 yuan)

	With Project		Without Project		Incremental	
Year	Case I	Case II	Case I	Case II	Case I	Case II
1	196.80	182.40			-196.80	-182.40
2			8.86	5.23	8.86	5.23
3			8.86	5.23	8.86	5.23
4			8.86	5.23	8.86	5.23
5			8.86	5.23	8.86	5.23
6			8.86	5.23	8.86	5.23
7			8.86	5.23	8.86	5.23
8			8.86	5.23	8.86	5.23
9			8.86	5.23	8.86	5.23
10			8.86	5.23	8.86	5.23
Total	196.80	182.40	79.73	47.09	-117.07	-135.31
PV	175.71	162.86	42.14	24.89	-133.57	-137.97
Irr					-15.06%	-20.96
Unit cost* (yuan/mwh)	1281.47	2070.00	280.00	280.00	-1001.47	-1790.00

*Electricity savings/mwh cost

In both cases, the project becomes more viable when power is valued at replacement cost rather than current price. As indicated in Table 7, at a 25 year life expectancy, per unit costs of building comparable generating and transmission capacity range from 979-1399 yuan/mwh. With the proposed project, per unit supply costs are 364-522 yuan/mwh. Net present values range from 100,830 to 123,160 yuan.

Table 7. Incremental Costs With and Without Project Using Overhead Lines at Replacement Cost (1,000 yuan)

	With Project		Without Project		Incremental	
Year	Case I	Case II	Case I	Case II	Case I	Case II
1	81.60	67.20	198.06	167.34	116.46	100.14
2			2.76	1.64	2.76	1.64
3			2.76	1.64	2.76	1.64
4			2.76	1.64	2.76	1.64
5			2.76	1.64	2.76	1.64
6			2.76	1.64	2.76	1.64
7			2.76	1.64	2.76	1.64
8			2.76	1.64	2.76	1.64
9			2.76	1.64	2.76	1.64
10			2.76	1.64	2.76	1.64
11			2.76	1.64	2.76	1.64
12			2.76	1.64	2.76	1.64
13			2.76	1.64	2.76	1.64
14			2.76	1.64	2.76	1.64
15			2.76	1.64	2.76	1.64
16			2.76	1.64	2.76	1.64
17			2.76	1.64	2.76	1.64
18			2.76	1.64	2.76	1.64
19			2.76	1.64	2.76	1.64
20			2.76	1.64	2.76	1.64
21			2.76	1.64	2.76	1.64
22			2.76	1.64	2.76	1.64
23			2.76	1.64	2.76	1.64
24			2.76	1.64	2.76	1.64
25			2.76	1.64	2.76	1.64
Total	81.60	67.20	264.30	206.75	182.70	139.55
PV	72.86	60.00	196.02	160.83	123.16	100.83
Irr						
Unit cost* (yuan/mwh)	363.70	522.01	978.51	1399.22	614.81	877.21

*Electricity savings/mwh cost

Table 8 shows comparable cost figures using cable lines at replacement costs for new generating capacity. Only in Case 2 using end of transformer reactors are investment and per unit costs higher than system capacity expansion. Per unit costs range from 877-1417 yuan/mwh with the project compared to 979-1399 yuan/mwh at capacity replacement costs. These figures suggest that depending on construction costs for new electric generating facilities even the more expensive cable line replacement scenarios may be competitive in terms of per unit cost.

Table 8. Incremental Costs With and Without Project Using Cable at Replacement Cost (1,000 yuan)

	With Project		Without Project		Incremental	
Year	Case I	Case II	Case I	Case II	Case I	Case II
1	196.80	182.40	198.06	167.34	1.26	-15.06
2			2.76	1.64	2.76	1.64
3			2.76	1.64	2.76	1.64
4			2.76	1.64	2.76	1.64
5			2.76	1.64	2.76	1.64
6			2.76	1.64	2.76	1.64
7			2.76	1.64	2.76	1.64
8			2.76	1.64	2.76	1.64
9			2.76	1.64	2.76	1.64
10			2.76	1.64	2.76	1.64
11			2.76	1.64	2.76	1.64
12			2.76	1.64	2.76	1.64
13			2.76	1.64	2.76	1.64
14			2.76	1.64	2.76	1.64
15			2.76	1.64	2.76	1.64
16			2.76	1.64	2.76	1.64
17			2.76	1.64	2.76	1.64
18			2.76	1.64	2.76	1.64
19			2.76	1.64	2.76	1.64
20			2.76	1.64	2.76	1.64
21			2.76	1.64	2.76	1.64
22			2.76	1.64	2.76	1.64
23			2.76	1.64	2.76	1.64
24			2.76	1.64	2.76	1.64
25			2.76	1.64	2.76	1.64
Total	196.80	182.40	264.30	206.75	67.50	24.35
PV	175.71	162.86	196.02	160.83	20.30	-2.03
Irr						9.73%
Unit cost* (yuan/mwh)	877.15	1416.88	978.51	1399.22	101.36	-17.67

*Electricity savings/mwh cost

Energy and Environmental Benefits

Table 9 shows incremental energy and environmental impacts with and without the project per transformer unit. Annual power savings range from 39.4 mwh in Case 1 (with the capacitor at the end user) to 23.5 mwh in Case 2 (with capacitor at the back side of the transformer). Coal savings range from 9.2 to 15.4 tce. Annual CO_2 emissions reductions range from 6.8 to 11.4 tons. SO_2 and TSP emissions are reduced by 0.2-0.4 and 0.3-0.4 tons, respectively.

Table 9. Energy and Environmental Impacts With and Without Project*

Item	Case 1	Case 2
1. Annual power savings (mwh)	39.43	23.46
2. Convert to coal savings (tce)	15.38	9.15
3. CO2 reduction (t)	11.43	6.80
4. SO2 reduction (t)	0.39	0.23
5. TSP reduction (t)	0.43	0.26

*Per unit transformer with capacity 315 KVA.

*Emission factor	(kg/mwh)
1. CO2	290.00
2. SO2	10.00
3. TSP	11.00

Economic/Environmental Assessment

Table 10 depicts the economic/environmental cash flow for the project under both cases I and II. The internal rates of return remain unchanged at -0.46 using lines and -6.58 using cable as electricity prices already reflect economic prices. With local environmental benefits, rates of return improve to -0.27 for lines and -6.32 for cable. The incremental cost of CO_2 reduction is 556 (case I) and 1068 (case II). Net benefits per ton CO_2 reduction range from -556 to -490 in case I and from -947 to -1069 yuan in case II.

Table 10. Incremental Economic/Environmental Cash Flow Analysis (1000 yuan)

					--------Emissions---------						Economic Value of Local			
			Net Benefits		Global		Local		Local		Emissions		Net Benefits	
	Total Costs		w/o Environ.		CO2(t)		SO2(t)		TSP(t)		Reduction		w/ Environ.	
Year	case (I)	case (II)	case (I)	case (II)	case (I)	case (II)	case (I)	case (II)	case (I)	case (II)	case (I)	case (II)	case (I)	case (II)
1	81.60	67.20	-81.60	-67.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-81.60	-67.20
2	-8.86	-5.23	8.86	5.23	-11.61	-6.91	-0.36	-0.21	-0.33	-0.19	0.09	0.05	8.95	5.28
3	-8.86	-5.23	8.86	5.23	-11.61	-6.91	-0.36	-0.21	-0.33	-0.19	0.09	0.05	8.95	5.28
4	-8.86	-5.23	8.86	5.23	-11.61	-6.91	-0.36	-0.21	-0.33	-0.19	0.09	0.05	8.95	5.28
5	-8.86	-5.23	8.86	5.23	-11.61	-6.91	-0.36	-0.21	-0.33	-0.19	0.09	0.05	8.95	5.28
6	-8.86	-5.23	8.86	5.23	-11.61	-6.91	-0.36	-0.21	-0.33	-0.19	0.09	0.05	8.95	5.28
7	-8.86	-5.23	8.86	5.23	-11.61	-6.91	-0.36	-0.21	-0.33	-0.19	0.09	0.05	8.95	5.28
8	-8.86	-5.23	8.86	5.23	-11.61	-6.91	-0.36	-0.21	-0.33	-0.19	0.09	0.05	8.95	5.28
9	-8.86	-5.23	8.86	5.23	-11.61	-6.91	-0.36	-0.21	-0.33	-0.19	0.09	0.05	8.95	5.28
10	-8.86	-5.23	8.86	5.23	-11.61	-6.91	-0.36	-0.21	-0.33	-0.19	0.09	0.05	8.95	5.28
Total	1.87	20.11	-1.87	-20.11	-104.48	-62.16	-3.25	-1.93	-2.94	-1.75	0.78	0.46	-1.09	-19.65
PV	30.71	35.11	-30.71	-35.11	-55.23	-32.86	-1.72	-1.02	-1.55	-0.92	0.41	0.24	-27.06	-31.13
IRR			-0.46%	-6.58%									-0.27%	-6.32%

Case I:	CO2	COAL
Total Incremental Cost/Ton of CO2 Reduction (yuan at 12%)	556.14	395.91
At RMB/US$ = 5.50	$101.12	$71.98
Total Net Benefits/Ton of CO2 Reduction (yuan at 12%)	(556.14)	(395.91)
At RMB/US$ = 5.50	($101.12)	($71.98)
Net Benefits Incl'g Local Env. Benefits/Ton of CO2 Reduction	(489.90)	(348.76)
At RMB/US$ = 5.50	($89.07)	($63.41)

Case II:	CO2	COAL
Total Incremental Cost/Ton of CO2 Reduction (yuan at 12%)	1068.58	760.71
At RMB/US$ = 5.50	$194.29	$138.31
Total Net Benefits/Ton of CO2 Reduction (yuan at 12%)	(1068.58)	(760.71)
At RMB/US$ = 5.50	($194.29)	($138.31)
Net Benefits Incl'g Local Env. Benefits/Ton of CO2 Reduction	(947.44)	(674.47)
At RMB/US$ = 5.50	$172.26	($122.63)

Miscellaneous Industries: Case 4
Energy Efficient Technology in Thermal Power Plants

Introduction

In 1990, the average net coal consumption for thermal power plants above 6,000 kw capacity was 427 gce/kwh, a figure 70-100 gce/kwh higher than industrial country averages. Differences are due in part to qualitative differences in coal. The remaining difference is attributed to high service rates, i.e. in-house losses in terms of power generation. House service rates in China average 8-9 percent, a figure 1-2 percentage points higher than rates in advanced industrial countries.

To address the issue of generating loss, the Ministry of Energy has recommended consolidation of operations to large capacity, high parameter units gradually shutting down small and medium scale generating facilities. The Ministry also has reviewed 24 energy saving techniques to conserve fuel or electricity. Among those techniques, five were emphasized for widespread application in thermal power plants. Those techniques include:

- renovated multi-function burners,
- heat tube air preheaters,
- axial classifiers,
- high efficiency ash slurry pumps, and
- high efficiency and variable speed water pumps.

Each of these techniques are examined below based on application at the Zhenhai Power Plant. One of the principal plants in the East China Power network, the Zhenhai plant has two 125 mw oil burning units and four 200 mw coal burning units. The average coal consumption of the plant is 376 gce/kwh, a figure that despite some in plant renovation remains 20-50 gce/kwh higher than comparable averages in industrialized settings.

Technology Assessment

Renovated Multi-Function Burner: Because coal fired plants are used for peaking power in China, oil burners are used to stabilize combustion. In general, for each 200 mw coal burning unit, 2400 tons of oil (600 tons of light oil and 1800 tons of heavy oil) are used annually, amounting to 0.7 percent of total energy consumption per unit. With renovation, small burner nozzles of 100-200 kg/h capacity are used to replace the standard 500-2000 kg/h nozzles. Burner renovation results in:

- oil savings during ignition and low load periods,
- greater use of pulverized coal rather than oil during ignition period, and
- combustion efficiency raised by 0.5 percent during normal operation.

Burner modification has been employed in more than 90 units to date with an additional 80 units in China for which renovation has not taken place.

Heat Tube Preheater: If air temperature within the tubes leading into the preheater falls below the dew point, condensation takes place causing an accumulation of ash and scaling within the tube. The buildup in time leads to corrosion and restricts airflow.

Using steam to preheat air to 50^{o}C before it enters the preheater, local condensation is prevented. Currently, 16 assemblies of this type of steam preheater are being used in the 670 ton/hour boiler at Zhenhai Power Plant. Steam consumption for preheating is 9 tons/hour.

An alternative approach uses a heat tube air preheater using flue gas to preheat the air within the tube. The temperature at the exhaust flue is lowered by 20-30^{o}C, and boiler efficiency is raised by 1-1.5 percent. To date, heat tube preheaters have been used in more than 20 boilers with capacity ranges from 65 to 670 tons/hour. Where applications have been made, net coal consumption has been lowered by 3-8 g/kwh, and coal savings per boiler can reach 2000-6000 tons annually.

Axial Classifier: Pulverized coal is passed through a classifier and then to a cyclone separator. Coarser materials fall back to the mill for regrinding. The original equipment uses longitudinal classifiers, which have inconsistent pressure and low separating efficiency. As a result, an excessive amount of pulverized coal is recycled affecting operational efficiency and increasing power consumption.

With an axial classifier, a more constant pressure is maintained, air flow increases, and less coal is returned for recycling. Power output increases and per unit power consumption decreases by 2 kwh per ton of pulverized coal. In a 400 ton/hour 125 mw boiler, annual power savings for each unit would be 0.86 gwh. At a price of 0.25 yuan/kwh, annual energy savings are valued at 217,000 yuan .

High Efficiency Ash Slurry Pump: The new ZJ-250 ash slurry pump replaces the original type 10 PH pump. The new pump is made of abrasion resistant chrome alloy cast iron with a life span prolonged from 1000-3000 hours to 6000 hours. The new pump reduces water consumption from 1:10 to 1:5 and eliminates the need for a shaft packing water pump thus reducing power consumption for slurry pump operations by eight percent. Overall, the pump operates with improved pump efficiency which means that smaller motors can be used resulting in annual power savings for each new pump of 0.5-1.5 gwh.

Variable Speed Feed Water Pump: A power plant boiler must be fed continuously with water while in operation. The load requirements vary depending on the output of the boiler which may vary between 50-100 percent. When feed water is supplied with a fixed speed pump, per unit power consumption rises. According to tests on a 125 mw oil burning unit at Zhenhai plant, unit power consumption is 7.4 kwh per ton of steam at full load but increases to 11.8 kwh per ton of steam at a 48 percent load. Over that load range, power consumption rises by 59.5 percent.

With a variable speed water pump, the pump speed can be reduced to meet the demand for feed water. Replacement of a 25 mw unit with a variable speed unit can produce annual energy savings of 4000 mwh.

Financial Analysis

Each of the five alternatives is evaluated separately and then collectively in terms of financial feasibility, energy conservation and environmental benefits. Summary tables for the combined project are listed below, while financial tables for each of the five alternatives considered follow as an appendix.

Investment and repair costs with and without the project are listed in Table 1 for each of the alternatives considered and for the combined project. Investment costs for the

entire project amount to 15.43 million RMB yuan with an additional 1.66 million yuan for repair costs. Without the project, 8.50 million yuan in investment and 2.72 million yuan in repair costs will be incurred. The heat tube preheater requires the highest investment cost at 7.0 million yuan followed by the high efficiency slurry pump and the high efficiency water pump at 3.3 and 2.7 million yuan, respectively.

Table 1. Summary of Investment and Repairs With and Without Project (1000 yuan)

	With Project		Without Project	
Item	Investment	Repairs	Investment	Repairs
1. Burner Renovation	1,560	375	20	
2. Heat Tube Preheater	7,000		2,800	
3. Coal Powder Separator	840		400	
4. High Efficiency Slurry Pump	3,330	480	4,320	1,920
5. High Efficiency Water Pump	2,700	800	960	800
Total Project	15,430	1,655	8,500	2,720

Table 2 indicates energy savings and incremental cash flow for the combined project incorporating all five alternatives. Energy savings continue to increase for the first six years after renovation begins. Ultimately, annual energy savings reach 47,107 tce. Of that total, 20,160 tce are in coal and steam usage and 17,402 mwh in power use.

Combined, the five alternatives generate a net present value of -72.81 million yuan which reflects cost savings with the project. The payback period is two years or one year after initial renovation. The internal rate of return is 195 percent which indicates that power plant renovations using these alternatives offer substantial energy benefits and extremely high financial returns. These modifications should be considered in retrofitting existing power plants.

Individually, all five of the alternatives offer high rates of return and rapid payback periods. Rates of return range from 89 percent to positive infinity for all of the projects. Burner renovation and high efficiency slurry pump offer the highest returns, while the heat tube preheater, the most expensive alternative, still offers a return of 259 percent and two year payback period.

Table 2. Summary of Energy Savings and Incremental Cash Flow

	Coal Use (tce)	Steam Use (tce)	Power Use (mwh)	Total (tce)	Total Cost (1000 yuan) Investment	Operating	Total
1	0.00	0.00	0.00	0.00	4663.00	0.00	4663.00
2	5040.00	5040.00	13307.00	15269.73	(47.00)	(8814.69)	(8861.69)
3	5040.00	5040.00	14672.00	15802.08	1355.00	(9087.69)	(7732.69)
4	10080.00	10080.00	16037.00	26414.43	97.50	(13019.73)	(12922.23)
5	10080.00	10080.00	17402.00	26946.78	695.50	(10480.82)	(9785.32)
6	15120.00	15120.00	17402.00	37026.78	423.50	(18646.02)	(18222.52)
7	20160.00	20160.00	17402.00	47106.78	345.50	(22305.06)	(21959.56)
8	20160.00	20160.00	17402.00	47106.78	(172.50)	(22305.06)	(22477.56)
9	20160.00	20160.00	17402.00	47106.78	(2442.50)	(22305.06)	(24747.56)
10	20160.00	20160.00	17402.00	47106.78	(844.50)	(22305.06)	(23149.56)
11	20160.00	20160.00	17402.00	47106.78	1363.50	(22305.06)	(20941.56)
Total	146160.00	146160.00	165830.00	356993.70	6740.00	(171574.27)	(166137.27)
PV	64209.22	64209.22	81715.19	160287.36	5087.45	(77899.04)	(72811.59)
IRR							194.79%
Energy savings cost (yuan/tce)				31.74			
Energy savings investment				317.40			

As with power use, atmospheric emissions reductions continue to increase for the first six years of the project as indicated in Table 3. At full operation, annual CO_2 emissions are reduced by 35,561 tons. Annual SO_2 and TSP emissions are reduced by 1,106 and 1,000 tons, respectively.

Table 3. Summary of Emissions Reduction - Entire Project

Year	CO2 (t)	SO2 (t)	TSP (t)
1	0.00	0.00	0.00
2	11527.27	358.38	324.18
3	11929.15	370.87	335.48
4	19940.52	619.95	560.78
5	20342.39	632.44	572.08
6	27951.89	869.02	786.08
7	35561.38	1105.60	1000.08
8	35561.38	1105.60	1000.08
9	35561.38	1105.60	1000.08
10	35561.38	1105.60	1000.08
11	35561.38	1105.60	1000.08

Emission	Power	Coal
1. CO2	294.41	754.91
2. SO2	9.15	23.47
3. TSP	8.28	21.23

Economic/Environmental Assessment

Table 4 depicts the economic/environmental cash flow for the project. Using economic prices, the internal rate of return increases from 194.8 to 249.6 percent due to energy savings. With local environmental benefits, the rate of return improves slightly to 251.5 percent. The incremental cost of CO_2 reduction is -742 RMB yuan per ton indicating that global environmental benefits are being realized at a negative economic

cost. Net benefits per ton amount to a positive 742 yuan increasing to 750 yuan per ton with local environmental benefits from reduced SO_2 and TSP emissions included.

Table 4. Incremental Economic/Environmental Cash Flow Analysis (1000 yuan)

Year	Total Costs	Net Benefits	Emissions Global CO2 (t)	Emissions Local SO2 (t)	Local TSP (t)	Econ Value of Local Pollution Reduction	Net Economic/ Environmental Benefits
1	4,663.00	(4,663.00)	0.00	0.00	0.00	0.00	(4,663.00)
2	(11,481.59)	11,481.59	11,527.27	358.38	324.18	85.79	11,567.39
3	(10,489.09)	10,489.09	11,929.15	370.87	335.48	88.79	10,577.88
4	(15,815.13)	15,815.13	19,940.52	619.95	560.78	148.41	15,963.54
5	(13,259.32)	13,259.32	20,342.39	632.44	572.08	151.40	13,410.72
6	(22,141.12)	22,141.12	27,951.89	869.02	786.08	208.04	22,349.16
7	(25,878.16)	25,878.16	35,561.38	1,105.60	1,000.08	264.67	26,142.84
8	(26,396.16)	26,396.16	35,561.38	1,105.60	1,000.08	264.67	26,660.84
9	(28,666.16)	28,666.16	35,561.38	1,105.60	1,000.08	264.67	28,930.84
10	(27,068.16)	27,068.16	35,561.38	1,105.60	1,000.08	264.67	27,332.84
11	(24,860.16)	24,860.16	35,561.38	1,105.60	1,000.08	264.67	25,124.84
Total	(201,392.07)	201,392.07	269,498.11	8,378.64	7,578.98	2,005.81	203,397.88
PV	(89,813.63)	89,813.63	121,002.53	3,761.94	3,402.90	900.59	90,714.23
IRR	249.64%						251.53%

	CO2
Total Incremental Cost/Ton of CO2 Reduction (yuan at 12%)	(742.25)
At RMB/US$ = 5.50	($134.95)
Total Net Benefits/Ton of CO2 Reduction (yuan at 12%)	742.25
At RMB/US$ = 5.50	$134.95
Net Benefits Incl'g Local Env. Benefits/Ton of CO2 Reduction	749.69
At RMB/US$ = 5.50	$136.31

APPENDICES

Table 1-1. Major Indicators With and Without Project for Burner Renovation

Items	With	Without
1. Oil injector for firing	4.00	4.00
2. Oil inject capacity (t/h)	0.15	1.50
3. Oil injector for burning	4.00	4.00
4. Oil inject capacity (t/h)	0.15	2.00
5. Annual light oil use (t)	180.00	600.00
6. Annual heavy oil use (t)	500.00	1800.00
7. Annual coal use for vs oil (tce)	2460.00	0.00
8. Light oil price (yuan/t)	1600.00	1600.00
9. Heavy oil price (yuan/t)	600.00	600.00
10. Coal price (yuan/tce)	240.00	240.00
11. Steam use (t/h)	0.25	0.08
12. Annual steam use (t)	833.33	67.50
13. Steam price (yuan/t)	37.80	37.80

Table 1-2. Investment and Repair Costs With and Without Project for Burner Renovation (1000 yuan)

	With Project		Without Project	
Year	Investment	Repair	Investment	Repair
1989	520.00		2.00	
1990		25.00	2.00	
1991		25.00		
1992	130.00	25.00		
1993	130.00	37.50	2.00	
1994		37.50	4.00	
1995	520.00	37.50	2.00	
1996		37.50		
1997	130.00	37.50		
1998	130.00	37.50	2.00	
1999		37.50	4.00	
2000		37.50	2.00	
Total	1560.00	375.00	20.00	0.00

Table 1-3. Incremental Cash Flow Analysis With and Without Project for Burner Renovation Project (1000 yuan)

Year	Investmt	Repairs	Light Oil	Heavy Oil	Coal Use	Steam	Total
1989	518.00	25.00					543.00
1990	(2.00)	25.00	(1344.00)	(1560.00)	1180.80	28.95	(1671.25)
1991	0.00	25.00	(1344.00)	(1560.00)	1180.80	28.95	(1669.25)
1992	130.00	37.50	(1344.00)	(1560.00)	1180.80	28.95	(1526.75)
1993	128.00	37.50	(2016.00)	(2340.00)	1771.20	43.42	(2375.88)
1994	(4.00)	37.50	(2688.00)	(3120.00)	2361.60	57.90	(3355.00)
1995	518.00	37.50	(2688.00)	(3120.00)	2361.60	57.90	(2833.00)
1996	0.00	37.50	(2688.00)	(3120.00)	2361.60	57.90	(3351.00)
1997	130.00	37.50	(2688.00)	(3120.00)	2361.60	57.90	(3221.00)
1998	128.00	37.50	(2688.00)	(3120.00)	2361.60	57.90	(3223.00)
1999	(4.00)	37.50	(2688.00)	(3120.00)	2361.60	57.90	(3355.00)
2000	(2.00)	0.00	(2688.00)	(3120.00)	2361.60	57.90	(3390.50)
Total	1540.00	375.00	(24864.00)	(28860.00)	21844.80	535.55	(29428.65)
PV	934.87	192.64	(10986.97)	(12752.73)	9652.84	236.65	(12722.70)
IRR							308.99%

Table 2-1. Major Indicators With and Without Project for Heat Tube Preheater

Items	With Project	Without
1. Steam use for heater or hot tube	0.00	9.00
2. Smoke emission temperature	145.00	165.00
3. Operation hour (h)	7200.00	7200.00
4. Coal saving with reduced smoke	5040.00	
5. Steam use coverts to coal (t)		5040.00
6. Price of coal (yuan/tce)*	240.00	240.00
7. Steam price (yuan/t)	37.80	37.80

*Economic CF for price of coal is 1.00

Table 2-2. Investment and Repair Costs With and Without Project for Heat Tube Preheater (1000 yuan)

	With Project		Without Project	
Year	Investment	Repair	Investment	Repair
1990	1400			
1991				
1992	1400			
1993				
1994	1400		700	
1995	1400		700	
1996				
1997				
1998			700	
1999			700	
2000	1400			
2001				
Total	7000	0	2800	0

Table 2-3. Incremental Cash Flow Analysis With and Without Project for Heat Tube Preheater(1000 yuan)

Year	Investment	Repairs	Coal Saving	Steam Use	Total
1990	1400.00	0.00			1400.00
1991	0.00	0.00	(1209.60)	(2449.44)	(3659.04)
1992	1400.00	0.00	(1209.60)	(2449.44)	(2259.04)
1993	0.00	0.00	(2419.20)	(4898.88)	(7318.08)
1994	700.00	0.00	(1209.60)	(2449.44)	(2959.04)
1995	700.00	0.00	(3628.80)	(7348.32)	(10277.12)
1996	0.00	0.00	(4838.40)	(9797.76)	(14636.16)
1997	0.00	0.00	(4838.40)	(9797.76)	(14636.16)
1998	(700.00)	0.00	(4838.40)	(9797.76)	(15336.16)
1999	(700.00)	0.00	(4838.40)	(9797.76)	(15336.16
2000	1400.00	0.00	(4838.40)	(9797.76)	(13236.16)
2001	0.00	0.00	(4838.40)	(9797.76)	(14636.16)
Total	4200.00	0.00	(38707.20)	(78382.08)	(38707.20)
PV	2922.99	0.00	(15965.75)	(32330.64)	(15965.75)
IRR					258.52%

Table 3-1. Major Indicators With and Without Project for Separate Coal Powder

Items	With Project	Without
1. System power use (kwh/t)	30.00	32.00
2. Annual operating hours (h)	7340.00	7340.00
3. Total power use (mwh)	20475.00	21840.00
4. Power price (yuan/mwh)	200.00	200.00

Table 3-2. Investment and Repair Costs With and Without Project for Coal Powder Separator (1000 yuan)

	With Project		Without Project	
Year	Investment	Repair	Investment	Repair
1990	140.00			
1991	140.00			
1992	140.00			
1993	140.00			
1994	140.00		100.00	
1995			100.00	
1996				
1997				
1998			100.00	
1999			100.00	
2000	140.00			
2001				
Total	840.00	0.00	400.00	0.00
NPV	544.92	0.00	175.66	0.00

Table 3-3. Incremental Cash Flow Analysis With and Without Project for Coal Powder Separator (1000 yuan)

Year	Investment	Repairs	Power Savings	Total	Power savings (MWh)
1990	140/00	0.00		140.00	
1991	140.00	0.00	(273.00)	(133.00)	1365.00
1992	140.00	0.00	(546.00)	(406.00)	2730.00
1993	140.00	0.00	(819.00)	(679.00)	4095.00
1994	40.00	0.00	(1092.00)	(1052.00)	5460.00
1995	(100.00)	0.00	(1092.00)	(1192.00)	5460.00
1996	0.00	0.00	(1092.00)	(1092.00)	5460.00
1997	0.00	0.00	(1092.00)	(1092.00)	5460.00
1998	(100.00)	0.00	(1092.0)	(1192.00)	5460.00
1999	(100.00)	0.00	(1092.00)	(1192.00)	5460.00
2000	140.00	0.00	(1092.00)	(952.00)	5460.00
2001	0.00	0.00	(1092.00)	(1092.00)	5460.00
Total	440.00	0.00	(10374.00)	(9934.00)	51870.00
PV	369.25	0.00	(4574.23)	(4204.98)	22871.13
IRR				194.94%	
Electricity savings cost (yuan/mwh)				16.14	
Energy savings investment (yuan/tce)				413.97	

Table 4-1. Major Indicators With and Without Project for Slurry Pump

Items	With	Without
1. Motor Capacity (kw)	850.00	850.00
2. Annual operation hours (h)	8760.00	8760.00
3. Load factor (%)	58.82	76.47
4. Power current (a)	50.00	65.00
5. Annual power use (mwh)	4380.00	5694.00
6. Power price (yuan/mwh)	200.00	200.00

Table 4-2. Investment and Repair Costs With and Without Project for Slurry Pump (1000 yuan)

	With Project		Without Project	
Year	Investment	Repair	Investment	Repair
1990	360.00	40.00	360.00	160.00
1991	270.00	40.00	360.00	160.00
1992	270.00	40.00	360.00	160.00
1993	270.00	40.00	360.00	160.00
1994	270.00	40.00	360.00	160.00
1995	270.00	40.00	360.00	160.00
1996	270.00	40.00	360.00	160.00
1997	270.00	40.00	360.00	160.00
1998	270.00	40.00	360.00	160.00
1999	270.00	40.00	360.00	160.00
2000	270.00	40.00	360.00	160.00
2001	270.00	40.00	360.00	160.00
Total	3330.00	480.00	4320.00	1920.00
NPV	1752.84	247.77	2229.97	991.10

Table 4-3. Incremental Cash Flow Analysis With and Without Project for Slurry Pump (1000 Yuan)

Year	Investmt	Repairs	Power Savings	Total	Power Savings (mwh)
1990	0.00	(120.00)		(120.00)	
1991	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
1992	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
1993	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
1994	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
1995	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
1996	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
1997	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
1998	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
1999	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
2000	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
2001	(90.00)	(120.00)	(788.40)	(988.40)	3942.00
Total	(990.00)	(1440.00)	(8672.40)	(11102.40)	43362.00
PV	(477.14)	(743.32)	(4179.72)	(5400.18)	18659.45
IRR					
Electric saving cost (yuan/mwh)					(25.57)

Table 5-1. Major Indicators With and Without Project for Water Pump

Items	With Project	Without
1. Motor Capacity (kw)	4000.00	4000.00
2. Annual operation hours (h)	7120.00	7120.00
3. Load factor (%)	71.63	85.67
4. Power current (a)	286.52	342.70
5. Annual power use (mwh)	20400.00	24400.00
6. Power price (yuan/mwh)	200.00	200.00

Table 5-2. Investment and Repair Costs With and Without Project for Water Pump (1000 yuan)

	With Project		Without Project	
Year	Investmt	Repair	Investmt	Repair
1993	2700.00	40.00		40.00
1994		40.00		40.00
1995		40.00		40.00
1996		40.00		40.00
1997		40.00		40.00
1998		40.00		40.00
1999		40.00		40.00
2000		40.00		40.00
2001		40.00	1600.00	40.00
2002		40.00		40.00
2003		40.00		40.00
2004		40.00		40.00
2005		40.00		40.00
2006		40.00		40.00
2007		40.00		40.00
2008		40.00		40.00
2009		40.00		40.00
2010		40.00		40.00
2011		40.00		40.00
2012		40.00	(640.00)	40.00
Total	2700.00	800.00	960.00	800.00

Table 5-3. Incremental Cash Flow Analysis With and Without Project for Water Pump (1000 yuan)

Year	Investment	Repairs	Power Save	Total	Power Save (mwh)
1993	2700.00	0.00		2700.00	
1994	0.00	0.00	(2400.00)	(2400.00)	8000.00
1995	0.00	0.00	(2400.00)	(2400.00)	8000.00
1996	0.00	0.00	(2400.00)	(2400.00)	8000.00
1997	0.00	0.00	(2400.00)	(2400.00)	8000.00
1998	0.00	0.00	(2400.00)	(2400.00)	8000.00
1999	0.00	0.00	(2400.00)	(2400.00)	8000.00
2000	0.00	0.00	(2400.00)	(2400.00)	8000.00
2001	0.00	0.00	(2400.00)	(2400.00)	8000.00
2002	0.00	0.00	(2400.00)	(2400.00)	8000.00
2003	0.00	0.00	(2400.00)	(2400.00)	8000.00
2004	0.00	0.00	(2400.00)	(2400.00)	8000.00
2005	0.00	0.00	(2400.00)	(2400.00)	8000.00
2006	0.00	0.00	(2400.00)	(2400.00)	8000.00
2007	0.00	0.00	(2400.00)	(2400.00)	8000.00
2008	0.00	0.00	(2400.00)	(2400.00)	8000.00
2009	0.00	0.00	(2400.00)	(2400.00)	8000.00
2010	0.00	0.00	(2400.00)	(2400.00)	8000.00
2011	0.00	0.00	(2400.00)	(2400.00)	8000.00
2012	0.00	0.00	(2400.00)	(2400.00)	8000.00
Total	1740.00	0.00	(26400.00)	(25300.00)	88000.00
Electricity savings cost (yuan/mwh)					44.80
Energy saving investmt (yuan/tce)					2297.46