Raising China's electric motor efficiency

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Abstract

Electricity consumption by electric motors in China is projected to grow from 1,400 TWh in 2006 to approximately 3,000 TWh in 2020, accounting for about 60 % of total electricity consumption in the country. Over 70 % of total motor electricity consumption is attributed to inefficient medium and large induction motor systems (with a capacity of no less than 10 kW/unit). Thus, improving energy efficiency in electric motor systems provides significant potential for energy savings. A number of energy technologies — including intelligent motor controllers, (computerised devices to minimise energy inputs according to the drive loads of the motor systems), have been developed to exploit this potential. The objective of this paper is to assess the cost-effectiveness of improving the energy efficiency of China's medium and large induction motor systems by using intelligent motor controllers. On-site interviews with technology investors and users have been undertaken. Financial and economic analyses have been carried out to justify cost-effectiveness. Two analytic scenarios have been designed to assess the impacts of energy efficiency policy on energy savings. CO_2 emissions mitigation due to the use of advanced technology has been estimated. Four barriers to using new and wider technologies have also been identified. This paper concludes that (1) using intelligent motor controllers in China is financially viable within a payback period of less than two years; and (2) CO_2 reduction could be over 570 million tons between 2007 and 2020.

Introduction

China is currently the second-greatest electricity generating country after the United States. It had installed capacity of 517 GW at the end of 2005, and generated 2,498 TWh of electricity, over 11 % of the world total in 20051. In the same year, newly commissioned capacity reached 75 GW and new construction began on 110 GW that is roughly equal to the whole capacity of power generation in France at the end of 2005. In 2006, China's additional installed new capacity was expected to be 75 GW (China CCTV, 2006). *See Table 1.*

Table 1. Power in China

	Installed capacity (GW)	Electricity generation (TWh)	Capacity factor (%)
2000	319.3	1368.5	49%
2001	338.5	1483.9	50%
2002	356.6	1654.2	53%
2003	391.4	1905.2	56%
2004	442.4	2194.4	57%
2005	517.2	2497.5	55%

Primary data source: CSPER (2006)

China's demand for additional power will continue given that China aims at quadrupling its per capita GDP between 2000 and 2020 and that China planned to end its history of power

1. Source: author's interview with China State Power Economic Research Centre (November 2006)

shortages. Over the past five years, the elasticity of electricity with respect to GDP (the annual growth rate of power consumption divided by the annual growth rate of GDP) has been constantly greater than 1 (*see Figure 1*). This means that power development has been faster than economic development due to its historically accumulated power shortages and the development of its energy intensive economy. If China keeps this elasticity between 1 and 1.5, and achieves its economic development target, in 2020 China's final electricity consumption will be close to 6,000 TWh, much more than 4,180 TWh: its quadrupling level in 2000[2].

Electric motors are the major electricity consumption equipment in China. In 2005, about 1,250 TWh or 50 % of total final generated electricity was used by motors. Large motors (with unit capacity no less than 10 kW) consumed about 1,100 TWh or 44 % of the total power supply of the country[3].

An electric motor converts electrical energy into mechanical energy. Most electric motors work by electromagnetism, but motors based on other electromechanical phenomena, such as electrostatic forces and the piezoelectric effect, also exist. The fundamental principle upon which electromagnetic motors are based is that there is a mechanical force on any current-carrying wire contained within a magnetic field. The force is described by the Lorentz force law and is perpendicular to both the wire and the magnetic field. Most magnetic motors are rotary, but linear motors also exist. In a rotary motor, the rotating part (usually on the inside) is called the rotor, and the stationary part is called the stator. The rotor rotates because the wires and magnetic field are arranged so that a torque is developed about the rotor's axis. The motor contains electromagnets that are wound on a frame. Electric motors are found in industry and commercial machines, and household appliances such as fans, exhaust fans, fridges, washing machines, pool pumps and fan-forced ovens.

The energy efficiency standards of the Chinese electric motors in general are 2 % - 8 % lower than the EU standards (Danish Energy Management 2005). Most motors in the Chinese market follow the design parameters of the International Electrotechnical Commission (IEC). The Chinese Minimum Energy Performance Standards (MEPS) for motors that was publicized in 2002 are equal to the minimum limit of the EU EFF2. The efficiency difference between EU EFF1 and EU EFF2 is roughly between 2 % (95 % - 93 %) for large motors (> 75 kW) and 8 % (84 % - 76 %) for small motors (about 1 kW).

Large motors and motor systems account for a major share of electric motor population in China. An on-site random survey on the distribution of the motor size in China was undertaken by a research team in 2005 for 269 motors and motor systems (Danish Energy Management 2005). Their results showed that 73 % of the surveyed motors and motor systems in China have capacity between 10 and 200 kW/unit, and about 25 % are of 10 kW/unit. The average capacities for the whole motor population and for the large motors are 41 kW/unit and 55 kW/unit. See *Figure 2*.

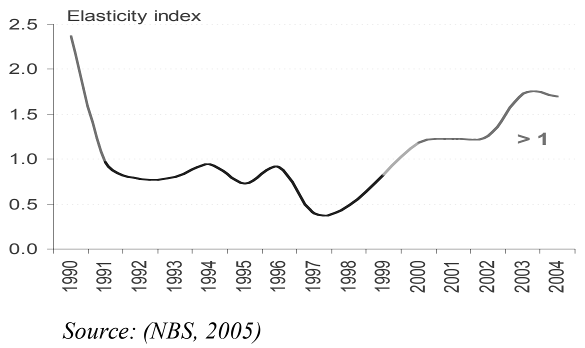


Figure 1. Elasticity of power to GDP

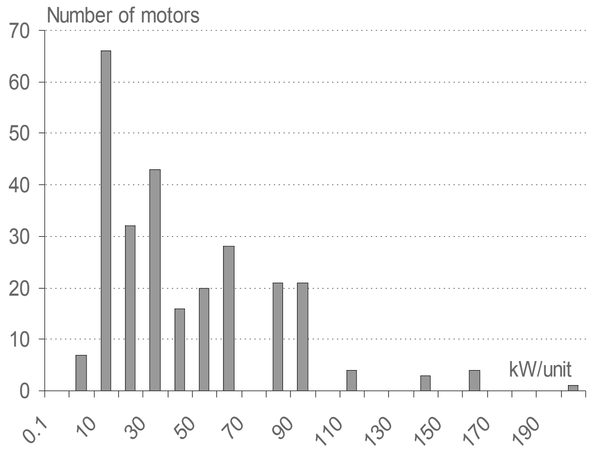


Figure 2. Motor capacity distributions

The average motor efficiency today in China is 89.9 % at 100 % load (Danish Energy Management 2005). If we were able to increase the average efficiency from 89.9 % to a technically achievable 96 %, China could save at least 76 TWh in 2005 and much more in 2020. Actually, most motors operate at level far below 100 % load. An on-site survey in seven Chinese industrial premises by the author in early 2000 revealed that over 60 % of motors are operating at 60 % of their rated load capacity. Idling, cyclic, lightly loaded or oversized motors consume more power than required even when they aren't working. These motors are wasting energy, generating extra utility billing costs and unnecessary motor wear to the users. Thus, there appears to be a significant potential of energy and cost savings in motor systems in China.

Fortunately, a number of technologies and measures have recently been developed to improve the energy efficiency for large motors and motor systems. These include intelligent motor controllers (IMCs) – computerized devices that optimize motor drive systems while maintaining constant motor speed. In France, Mexico, the UK and the USA, IMCs have been used to raise the energy efficiency for large motor systems.

The objective of this paper is to assess the effectiveness of using intelligent motor controllers to save electricity in motors and motor systems in China. We collected data by interviews with technology investors and users, and undertook a financial

2. In 2000, China's total final electricity consumption was 1,044 TWh.

3. Source: Author's personal communication with China State Power Economic Research Centre (2006)

and economic assessments program to justify cost-effectiveness. Two analytical scenarios (business as usual (BAU) and energy efficiency policy (EE) scenarios) were designed to assess the impacts of energy efficiency policy on electricity savings and CO_2 mitigations. We also identified a number of barriers to using IMC technologies in China.

This paper consists of five sections. In the next section, we present the methodology used in the study. We then review the state of the art of intelligent motor control systems and the most recent applications of this technology in France and Mexico. In a next section, which is the core of this paper, our cost-effectiveness analysis procedures and results are demonstrated. Finally, conclusions and policy recommendations are presented.

Methodology and approaches

A top-down analytical methodology is used to perform the study. It starts from the national macro level to project final electricity consumption in China and down to micro project financial analysis. A methodology framework is presented in *Figure 3*. The methodology is designed according to the availability of the data to accomplish various analyses under the BAU and EE scenarios. Our quantitative analysis methodology includes projection of total final electricity consumption in China by large motors, design of two scenarios, calculation of energy savings and power demand avoidance by using IMCs, pollution reductions, and cost-benefit estimations from the perspectives of the national government and the individual investors of the IMC devices.

Over one hundred interviews (20 random interviews with electric motor users in Bangladesh, 90 personal contact and random interviews with electric motor designers and users in China), and one experiment of an IMC device with an induction motor in France have been undertaken to collect data. The selection of the interviewees was recommended by power utilities in Bangladesh and China, and the selection of the experiment of the French IMC device was recommended by an IMC developer in the UK. Following the recommendation of the UK IMC developer, the author also interviewed by phone with an investor in Mexico who has installed over 100 IMCs in a Mexican company, and with an IMC technology-providing firm in the USA to verify the collected data.

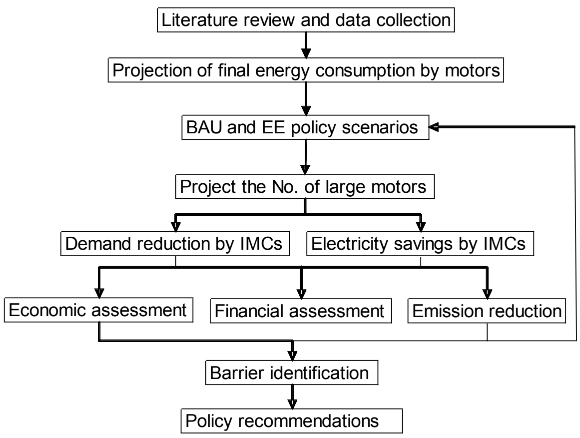


Figure 3. Methodological Framework

On the basis of the historical power consumption data (NBS 2005), with regression, we derived a time series econometric model and use the model to project future final electricity consumption in China and by large motors and motor systems. The regression models are shown in *Equation 1* and *Equation 2*. We further assumed the consumptions will follow these trends until 2020:

Equation 1: Total final electricity consumption in China

$$E_{total} = 205.1 \times e^{0.0802\times(t-1980)}$$

Where:
E (in TWh) is electricity consumption by large motors in year t.
e is the base of natural logarithm (= 2.71828).
t is any year between 2007 and 2020.

Equation 2: Final electricity consumption by large electric motors in China

$$E_{total} = 91.7 \times e^{0.079\times(t-1980)}$$

While testing and maximizing the autocorrelation or minimizing the heteroscedasticity between the regression function (model data set) and the real data, we tried to maximize the correlation coefficient of the two data sets, given that there is just one scalar-valued regressor in the model[4]. In doing so, we built a function that can calculate the correlation coefficients of the real data and model data in an MS-spreadsheet. With trial-and-errors to maximize value of the correlation coefficient, we derived the parameters of *Equation 1* and *Equation 2*.

When calculating the number of electric motors, we used the following model:

Equation 3: The number of large motors and motor systems in China

$$N = \frac{D_C}{C_f \times U \times L_f}$$

Where:

- N (in thousand) is the total number of large motor and motor systems in China in year t.
- D_c (in GW) is the capacity demand by large electric motor and motor systems in year t.
- C_f *(in %)* is the coincidence factor of the motor running. This was set at 0.37 based on the assumption: the motors are running 3200 hours a year on average.
- L_f (in %) is the load factor of the electric motors. We set it at 60 %, the same data as we collected from interviews.
- U (in kW/unit) is the average unit capacity of the induction motors in China. We used 55 kW, the survey result of the Danish Energy Management (2005).

4. See more information on this at http://en.wikipedia.org/wiki/Coefficient_of_determination

The BAU and EE scenarios are designed on the basis of our literature review, phone interviews with the IMC providers, and a number of Chinese policy makers in NDRC and professionals in the State Power Economic Research Centre. In the BAU scenario, the Chinese government and industry will not make effort in the application of IMCs. By 2020, only 0.1 % motors will be equipped with IMCS. In the EE scenario, due to the government policy, 9 % of the total large motor population will be equipped with IMCs. More detailed assumptions about the scenarios are presented in the section: "Case Study in China". We also performed several rounds of trial-and-error calculations to estimate the impacts of different policy scenarios before finalizing the energy efficiency policy scenario in the study. Under these two scenarios, simple MS-Excel spreadsheet models are developed to perform the calculations of electricity savings, demand reduction, economic and financial assessment, and GHG reduction.

While undertaking the economic cost-estimation, we only took the device production costs into account, but not the costs of policy development and information campaigns which are difficult to quantify. In the financial analysis, from the perspective of the owners of IMCs, the analysis was based on one piece of the device. This method will simplify the analysis and will not harm the results.

The annual cut of power generation is calculated from the annual cut of demand taking into account the power transmission and distribution (T&D) losses of 15 %. While calculating the avoidable investment in power generation, we assumed USD 1,330/kW as the capital cost with a deduction of government tax (31 %) but without adding the costs of investment in power T&D networks. The number of IMCs is derived from the following assumptions: (1) 55 kW/unit for motor system capacity as calculated from the survey of the Danish Energy Management (2005); (2) 0.37 for motor operation coincidence factor (3200 hr/yr divided by 8760 hr/yr); and (3) 60 % for average load factor of the motors.

In the following, we further present our literature review results, apply the collection data into the above mentioned methodology, perform analysis and present our results.

Power System and Intelligent Motor Controllers

In a purely resistive alternating current (AC) circuit system, voltage and current waveforms are in step, changing polarity at the same instant in each cycle. Where reactive loads are present, such as with capacitors or inductors, energy storage in the loads result in a time difference between the current and voltage waveforms. This stored energy returns to the source and is not available to do work at the load. A circuit with a low power factor will have thus higher currents to transfer a given quantity of power than a circuit with a high power factor. Power systems containing only heating elements (filament lamps, strip heaters, cooking stoves, etc.) have a power factor of 1.0. Power systems containing inductive or capacitive elements (lamp ballasts, motors, etc.) often have a power factor below 1.0.

AC power flow has three components: real power (P), measured in watts (W); apparent power (S), measured in volt-amperes (VA); and reactive power (Q), measured in reactive volt-amperes (VAr).

The power factor is defined as:

$$Cos\varphi = \frac{p}{Q}$$

Where φ is the phase angle between the current (I) and voltage (V). See *Figure 4.*

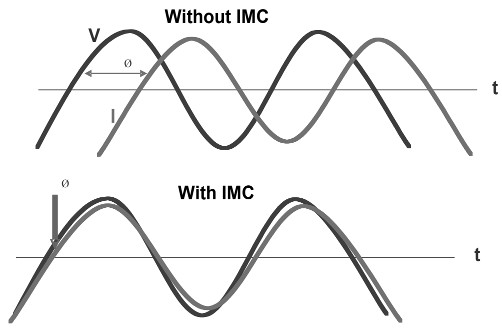
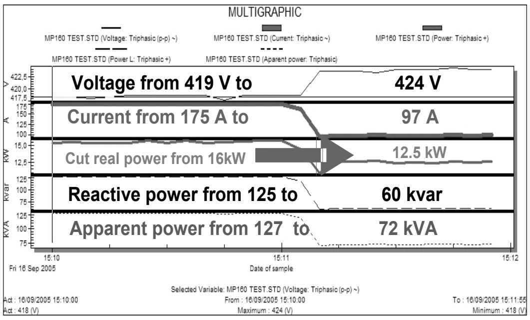


Figure 4. IMC improves system power factor

The significance of power factor lies in the fact that utility companies supply customers with volt-amperes, but bill them for watts and/or kWh. Power factors below 1.0 require a utility to generate more than the minimum volt-amperes necessary to supply the real power (watts). This increases generation and transmission costs. Good power factor is considered to be greater than 0.85 or 85 %. Utilities may charge additional costs to customers who have a power factor below some limit.

An intelligent motor controller, a computerized device, saves energy by measuring the work load on the motor by comparing the difference in voltage and current waveforms at the motor. This information is then used to raise the power factor of the motor and reduce the current and voltage to match the work load as required by the motor, while maintaining constant speed. This transaction takes place 120 times per second which prevents the motor from stalling under any and all changes to motor load conditions. *Figure 4* illustrates an IMC compensate reactive power and improve power factor. Because the IMC can adjust power consumption proportional to motor loading conditions without altering motor revolutions per minute (RPM), it reduces φ or raises cosφ of the power system, cuts excess current which is normally dissipated as heat. As a result, the motor runs more coolly and more quietly and with less vibration, saving energy, cutting down operation costs, and extending motor life. Nowadays, an IMC can be integrated into induction motor during the manufacturing of a new motor. It can also be made individually and installed to existing or old motors externally.

Practically, with an IMC, an induction motor can save up to 20 % of energy. *Figure 5* shows a real on-site measurement of power consumption by a motor system in France under two conditions: with and without an IMC. With the IMC, the induction motor raises system voltage rather than reduces it. It cuts more than half of reactive power. The IMC helped cut down 3.5 kW of power for a 16 kW motor system, saving 22 % of power consumption.



Source: Survey from PowerBoss France (2006)

Figure 5. IMC saves energy and improves system power factor

According to another on-site survey study in Mexico, investing in IMCs is financially viable. Over the past few years, INTELSTEER Co Ltd, an international energy service company (ESCO), has invested millions of dollars in IMC business in Mexico and Singapore. In Mexico, the ESCO has installed over 100 IMC units for a single industrial customer. The ESCO has recently undertaken a post-investment evaluation. *Table 2* highlights the results of the study. The average capital cost of the 102 IMC units was about USD 3,740/unit. The investment was recouped in 1.5 years. An IMC saves real power consumption by about 20 % or electricity consumption by 1.27 MWh/unit/yr. After installing an IMC, the users will reduce their electricity bills by USD 2,400/unit/yr. In addition, each IMC helps reduce 880 kg of CO_2 emissions annually.

Table 2. Survey results from Mexico

IMC Investment (USD/102 units)	381,000
Real power savings	19%
Electricity savings (MWh/yr)	130
Bill reduction (USD/yr)	243,840
Payback period (yr)	1.5
CO_2 reduction (tons/yr)	90

Source: INTELSTEER Co Ltd (2006)

An IMC also cuts down the starting current and extends the lifetime of motors. Full voltage hard starts can damage motors as well as equipment. An IMC can control the inrush of current, prevents unnecessary excess torque and reduces power grid disturbances. The soft-start circuit in the motor controller senses the motor load and the power to the motor. It then applies only the exact power required to start the motor without reducing the necessary starting torque or RPM. Actual kW demand is reduced and the power factor is improved. According to a test by INTELSTEER Co Ltd in 2006, an IMC reduces the peak current by over 50 % at the staring period of a motor operation. *Figure 6* shows the reduction of starting current of the motors by using the IMC.

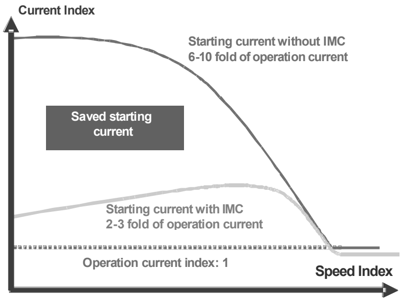


Figure 6. IMC saves starting current

Case Study in China

ASSUMPTIONS OF BUSINESS AS USUAL AND ENERGY EFFICIENCY SCENARIOS

In this case study, we made some assumptions and designed two scenarios: business as usual (BAU) and energy efficiency policy (EE). The assumptions which apply to both scenarios are as follows:

- Weighted average capacity of medium and large motors: 55 kW/unit, calculated from the survey results of Danish Energy Management (2005).
- Motor's average running time: 3200 hours/yr/unit (16 hours per day and 200 days a year). Thus, the coincidence factor of motor running is 0.37.
- China's power load factor: 55 %, calculated from the data of CSPER (2006). See *Table 1*.
- Between 2000 and 2020, electricity consumption by large motors and motor systems will increase as projected in *Figure 7*.

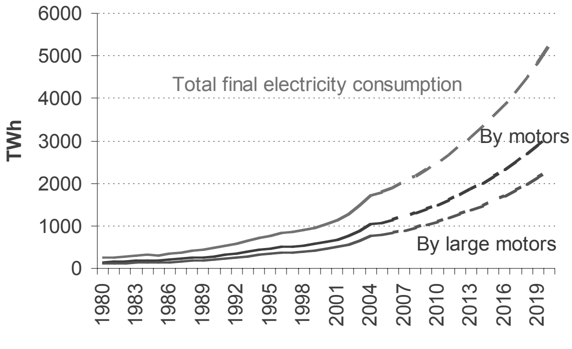


Figure 7. Total electricity consumption and shares by motors

- Electricity price is USD 0.05/kWh (in 2005 price) in 2006. This price will gradually grow up to USD 0.1/kWh (in 2005 price) in 2020.
- Discount rates are 12 % for national economic assessment, and 20 % for financial investment assessment. This rate was calculated on the basis of experience: (1) the payback period of investing in energy efficient products is expected to be

less than three years; (2) the economic lifetime of the appliance is seven years.

In the BAU scenario, we assume that the government, investors and the stakeholders of the induction motors will not rely on IMC technologies to a great extent. Specifically, the BAU scenario contains the following features:

- The average energy efficiency of induction motors will be 60 % and the load of the motors will be 60 %.
- By 2020, only 0.1 % motors will be installed with intelligent motor controllers due to natural penetration of the technology in China.

In the EE policy scenario, the government, private investors, motor manufacturers, and consumers will take actions to use IMCs. Specifically, the following key features describe the EE scenario:

- From 2007, IMC technologies will penetrate to the large induction motors in the market at 1 % of the large motors at the first years, and gradually increase and accumulatively approach 9 % of the total large motor population by 2020.
- Each IMC device will save 20 % of power.
- Total marginal cost of an IMC device is USD 2,925, including USD 1,950/unit capital cost and USD 975/unit of installation cost.
- Annual marginal O&M cost of the device is 5 % of the capital investment and installation costs at the second year of the installation. This cost will grow at the rate of 3 % per year up to 2020.
- The national government will make new standards for induction motors to promote IMC technologies.

PROJECTION RESULTS OF POWER CONSUMPTION BY LARGE INDUCTION MOTORS BY 2020

As mentioned in the section of methodology and approaches, we used *Equation 1* and *Equation 2* to project the total electricity consumption and electricity consumption by large motors and motor systems in China.

Table 3 presents the results. The data in the first column of the table was copied from the statistical yearbook of China (NBS, 2005). The second column was calculated from *Equation 1*. Comparing the data between 1998 and 2005 in the two columns, one can see that the modeling results fit well the actual data, with the coefficient of determination (R2) equal to 0.9929. The rest three columns of the table show electricity consumption by large motors under BAU and EE scenarios. Induction motors will consume about 3,000 TWh or 60 % of the total electricity use in China, and large induction motors and motor systems will use over 2,500 TWh electricity or 44 % of the total by 2020 under BAU scenario.

ELECTRICITY SAVINGS UNDER THE EE SCENARIO

We calculated electricity savings between the BAU scenario and the EE scenario. *Table 4* and *Figure 4* show the results. Under the BAU scenario, total final electricity consumption in China will grow exponentially from less than 1,800 TWh in 2006 to over 5,900 TWh in 2020. During this period, using IMCs under the assumptions of total 20 % penetration rate of large motors will save about 795 TWh of electricity. The accumulated cut of power capacity demand will be about 8.2 GW that is equivalent to 16 large power plants with 500 MW each.

ENVIRONMENT BENEFITS

We estimated the environment benefits achieved by installing IMCs to large induction motors in China. In 2002, China's shares of electricity production were 80.7 % from coal, 2.8 % from oil and 1.5 % from natural gas. By 2020, these shares will become 78.9 %, 1.62 % and 4.9 % respectively (WEO, 2005).

According to the Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC), China will mainly use critical and supercritical technologies in power generation in the next 15 years (ERI, 2005). The emission factors for such technologies are: 833 gCO_2/kWh, 6.7 gSO_2/kWh, and 2.6 gNO_x/kWh. For oil-fired power plants, we assume the emission factors are half those from the above-mentioned coal-fired plants. For natural gas-fired plants, the emission factors are 174.2 gCO_2/kWh, none for SO_2 and 0.3 gNO_x/kWh (ERI, 2005). Then, between 2007 and 2020, IMCs will bring about a reduction of 575 million tons of CO_2, 4.6 million tons of SO_2, and 1.8 million tons of NO_x in China. See *Table 4* and *Figure 8*.

COST-BENEFIT ASSESSMENTS

We also briefly undertook cost-benefit assessments from both the national capital investment perspective and the micro IMC investor's financing perspective. While doing the financial assessment, we performed the calculation on the basis of one unit of IMC investment. This simplified our analysis but did not harm the results for decision making.

National investment assessment

On the basis of the data of avoidable power demand by using IMCs each year in *Table 4*, we estimated the avoidable capital investments in power plants in China. The annual avoidable power generation is calculated from the annual avoidable demand taking into account 15 % of the power T&D losses. IMCs will help avoid power generation capacity from 0.36 GW in 2007 to 0.7 GW in 2020. The savings of the capital investment in the power generation capacity will be much more than the national capital expenditure in IMC technologies.

The IMC technologies will enforce China's energy security by avoiding billions of dollars in investing in new power plants. On 3 January 2006, China[5] announced its plans to build 32 nuclear power plants in the next 15 years to meet the country's burgeoning energy needs. By 2020, the country's total nuclear generating capacity will reach 40 GW and account for 4 % of the nation's total (State Power Corporation, 2006). On average, the capacity of each of the new nuclear power plants will be about 1 GW (500 MW/unit X 2 units). The application of IMCs in China under our energy efficiency scenario will thus avoid or postpone the installation of over eight large nuclear power plants. According to the IEA (2005), overnight construction capital cost for nuclear power plant ranged from

5. Source: Mr Shen Wenquan, Vice Director of the state-run China National Nuclear Corporation.

Table 3. Model regression and projection results

	Final electricity consumption (TWh)		Electricity consumption by large motors		
			Under BAU (TWh)		Under EE (TWh)
Year	Actual data	Modeling results	Actual data	Modeling results	Modeling results
1980	248	240	109	105	
1981	255	260	112	114	
1982	271	282	119	123	
1983	292	305	129	134	
1984	314	331	138	145	
1985	309	358	136	157	
1986	338	388	149	170	
1987	373	421	164	184	
1988	410	456	181	199	
1989	438	494	193	216	
1990	482	535	212	234	
1991	524	580	231	254	
1992	581	628	256	275	
1993	643	681	283	298	
1994	719	738	283	323	
1995	767	799	337	350	
1996	835	866	367	379	
1997	863	938	380	410	
1998	896	1017	394	445	
1999	950	1102	418	482	
2000	1044	1193	459	522	
2001	1136	1293	500	566	
2002	1264	1401	556	613	
2003	1483	1518	652	664	
2004	1721	1645	757	720	
2005	1790	1782	788	780	
2006		1931		845	845
2007		2092		915	881
2008		2267		992	941
2009		2456		1075	1002
2010		2661		1164	1068
2011		2884		1262	1138
2012		3125		1367	1213
2013		3385		1481	1305
2014		3668		1605	1405
2015		3974		1739	1512
2016		4306		1884	1629
2017		4666		2041	1755
2018		5056		2212	1892
2019		5478		2396	2040
2020		5935		2597	2200
	R Square = 0.9929				

Source of actual data: NBS (2005)

Table 4 Power savings and pollution reductions by IMCs

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total final electricity use (TWh)	1931	2092	2267	2456	2661	2884	3125	3385	3668	3974	4306	4666	5056	5478	5935
Use by large motors under BAU (TWh)	788	850	921	998	1081	1171	1269	1375	1490	1614	1749	1895	2053	2224	2410
Use by large motors under EE (TWh)	788	850	917	990	1064	1143	1228	1320	1430	1549	1679	1819	1971	2135	2314
Energy savings by IMC (TWh)	0	3.7	8.0	17.3	28.1	40.6	55.0	59.6	64.6	70.0	75.8	82.1	89.0	96.4	104.5
Capacity cut by IMC (GW)	0	0.3	0.6	1.4	2.2	3.2	4.3	4.7	5.1	5.5	5.9	6.4	7.0	7.6	8.2
GHG reduction (million tCO_2)	0	0	3	7	14	23	34	46	50	54	58	63	68	74	80
SO_2 reduction (kton)	0	0	25	53	116	188	272	368	399	433	469	508	550	596	646
No_x reduction (kton)	0	0	10	21	45	73	106	143	155	168	182	197	214	231	251

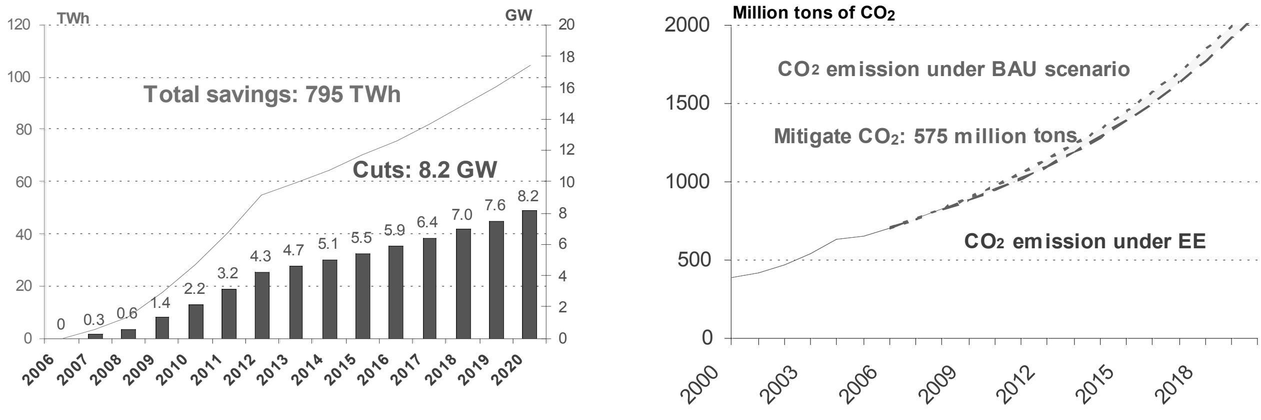


Figure 8. IMCs save power and cut emissions

Table 5 Savings of national capital investment

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Annual cut of demand (GW)	0.3	0.3	0.7	0.8	1.0	1.1	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6
Annual cut of generation (GW)	0.3	0.4	0.9	1.0	1.2	1.3	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.7
Avoidable investment in power (million USD)	140	163	354	411	475	547	175	189	205	222	241	261	282	306
Units of IMC investment (000)	72	84	182	211	244	281	90	97	105	114	123	134	145	157
Capital investment in IMCs (million USD)	-97	-113	-244	-284	-328	-378	-121	-131	-141	-153	-166	-180	-195	-211
Investment cash flow (million USD)	43	51	110	127	147	169	54	59	63	69	75	81	87	95
NPV at discount rate of 12% (million USD)	582													

USD 1,074/ kW in Korea to USD 2,510/kW in Japan. This figure in China in the 1990s was between USD 1,330/kW and USD 2,200/kW. In this study, we assume the Chinese will be able to keep the construction cost at USD 1,3304/kW6 in the forthcoming 15 years. Then, the total avoidable capital investment costs (without taking into account time value) will reach USD 3.9 billion. This results in positive cash flows in all years from 2007 up to 2020. The net present value of the national program of IMCs under the current scenario is USD 582 million. See *Table 5*.

Financial assessment

A financial assessment is carried out on the basis of one piece of IMC device. The major initial cost of the project (USD 2,925/ unit) is the sum of the initial equipment investment cost (USD 1,950/unit) and installation costs (50 % of equipment investment cost). The payback period of the investments is less than two years. The net present value (NPV) under the discount rate of 20 % is about USD 6,500 if the customer invests USD 2,925 for one piece of IMC with a 55 kW motor system. Consequently, the investment appears financially viable under these assumptions. *See Table 8*.

Table 6 Financial analysis results

	Cost	Electricity Price	Savings		Net values
	USD/unit	USD/kWh	kWh/day	USD/unit/yr	USD/unit
2007	2,925	0.05	176	880	-2,045
2008	146	0.05	176	1,886	1,739
2009	151	0.06	176	2,011	1,861
2010	155	0.06	176	2,137	1,982
2011	160	0.06	176	2,263	2,103
2012	165	0.07	176	2,389	2,224
2013	170	0.07	176	2,514	2,345
2014	175	0.08	176	2,640	2,465
2015	180	0.08	176	2,766	2,586
2016	185	0.08	176	2,891	2,706
2017	191	0.09	176	3,017	2,826
2018	197	0.09	176	3,143	2,946
2019	202	0.09	176	3,269	3,066
2020	209	0.10	176	3,394	3,186
NPV					**6,538**

Barriers to investing in IMCs

Despite the attractive benefits, there are a number of barriers preventing the uptake of IMCs in China, although investing in IMCs is economically and financially viable. Our telephone interviews with a number of investors and Chinese industrial stakeholders revealed the following major barriers:

- The purchasers of motors are generally not the end users. Motor users receive motors embedded in other equipment. As a result, the energy cost savings do not benefit the purchaser, which creates a split incentive similar to the landlord-tenant dilemma.
- Not many industrial stakeholders are aware of the IMC technologies. When compared with other energy efficient technologies such as CFL and/or variable speed drive motor systems. IMCs represent a new technology.
- Initial capital investment is high. When compared to the capital costs of other energy efficiency devices or even electric motors, the IMC investment is high. Users are usually hesitant to pay high front costs for energy efficient equipment.
- There is a lack of standards for high energy efficient motors. As indicated in the literature review, the Chinese energy efficiency standards for motors are generally lower than that of the EU. The standards do not have mandatory codes to raise energy efficiency for induction motors.

Policy recommendations

On the basis of our study, to reap the potential electricity savings in motors, the following policy measures are recommended to the Chinese government:

- Higher energy efficiency standards and codes for large induction motors should be developed and implemented. For large motors that are newly produced and sold, a built-in IMC device should be equipped. For existing large motors, external IMCs should be installed step by step during the forthcoming years.
- The national and local governments should widely use public media to promote IMC technologies, as for CFLs and other energy efficient technologies.
- Develop new financial mechanisms to overcome the barrier of high front investment costs of the technology. One example may include good collaboration among investment banks, investors or ESCOs, power utility and motor users: (1) the bank provides soft-loans to the investors or ESCOs who are purchasing the IMC technologies and installing them for the motor users, (2) the power utilities help collect saved money from the users due to the use of the IMC technologies, and pay the money back to the investors or ESCOs, and then the bank.

Conclusions

China's power consumption has been greatly increasing over the past 20 years and will continue to grow in the next 15 years. On the other hand, electricity use has been becoming increasingly inefficient over the past five years given that the elasticity of power consumption to GDP has been over 1. Without effective policy and technology measures, China will have missed its target of energy consumption plan by 2020: only double energy consumption while quadrupling GDP. There is a need to raise energy efficiency in China.

The use of IMC technology in China offers large potential for China to cost-effectively implement energy efficiency. Over 40 % of electric power is consumed by large induction motors in China. If 20 % of the induction motor population is equipped with IMC technologies by 2020, China will be able to cut over 8 GW of power demand, save over 795 TWh of electricity between 2007 and 2020, and mitigate 575 million tons of CO_2, 4.6 million tons of SO_2 and 1.8 million tons of NO_x.

Installing and operating IMCs in China is both financially and economically viable. Even under the most conservative scenario, the economic benefits which do not include the environment benefits will outweigh the marginal costs. The results of the financial analysis also show that the payback period for investors in IMCs will be less than two years. The net present value of investing one piece of IMC is over USD 6,500.

There are a number of barriers to the application of the IMC technologies in China. The government and industrial stakeholders need to work hard to promote IMCs in order to achieve the electricity savings and GHG reduction mentioned above. The priority for the Chinese government policy makers is to update the standards and codes for China's motor and motor systems.

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