

# Estimation of Potential Electricity Export from Amur region to China

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**Abstract.** – The paper deals with operating and economic problems in estimation of electricity export from Amur region to China. In JSC “Vostok” there are above 4000 MW of unused capacity of power plants that can be utilized for electricity generation for export. To accomplish this construction of export transmission lines is required. The maximum transmitted power depends to a great extent on the system of voltage and reactive power control. The limiting export tariff \$0.04/kWh is higher than the electricity cost at power plants and much lower than the electricity cost in the wholesale market. Export is profitable only over export transmission lines.

**Keywords:** Power system conditions, power quality, electricity tariffs.

## I. ARRANGEMENT OF ELECTRICITY EXPORT IN THE FAR EAST FROM RUSSIA TO CHINA

JSC “Vostochnaya energeticheskaya kompaniya” (VEK) (the Russian operator of the project on electricity export to China, a 100% subsidiary of INTER RAO EES) is in charge of electricity export abroad from the Far-Eastern power systems [1]. It concludes agreements on electricity supplies and draws up plans on construction of facilities intended for electricity export. In 2010 the company is planning to export 1,000,000 MWh of electricity to China. “Additional agreement to the Contract on the border trade” of February 17, 2009 was the legal authority for continuation of electricity supplies in the current year. This agreement between JSC “VEK” and the State Grid Corporation of China was signed in the late December 2009.

In the coming years the first priority projects

are construction of a 500 kV transmission line 126 km long at the cost of 3.3 billion rubles from Amurskaya substation to the state border, construction of a 400 MW combined cycle power plant at the cost of 12.6 billion rubles in Khabarovsk, construction of Erkovetskaya 1200 MW thermal power plant at the cost of 33.3 billion rubles in Amur Region. The transmission line and the combined cycle power plant are already under construction.

Further the feasibility analysis of electricity export project from Amur Region to China over the 500 kV export transmission line is carried out.

## II. ESTIMATION OF ADMISSIBLE POWER TRANSMISSION FROM BLAGOVESHCHENSK AREA TO CHINA BASED ON VOLTAGE AND REACTIVE POWER CONTROL

The system of voltage and reactive power control has a pronounced effect on the limiting transmitted power over tie lines among power systems.

The scheme of power transmission to China is given in Fig. 1. Surplus power from Zeiskaya and Bureiskaya hydro power plants (HPPs) is transmitted through Amurskaya substation to Blagoveshchensk. The distance from Zeiskaya HPP to Blagoveshchensk is 482 km, from Bureiskaya HPP – 397 km. From Blagoveshchensk substation power is transmitted by the export transmission lines 110, 220 and 500 kV to Heihe city in China. It should be noted that the power transmission scheme presented in Fig. 1 does not satisfy the n-1 reliability criterion because of the use of single-circuit 500 kV transmission lines and therefore, the electricity export should be considerably decreased, when one of 500 kV transmission lines is tripped.

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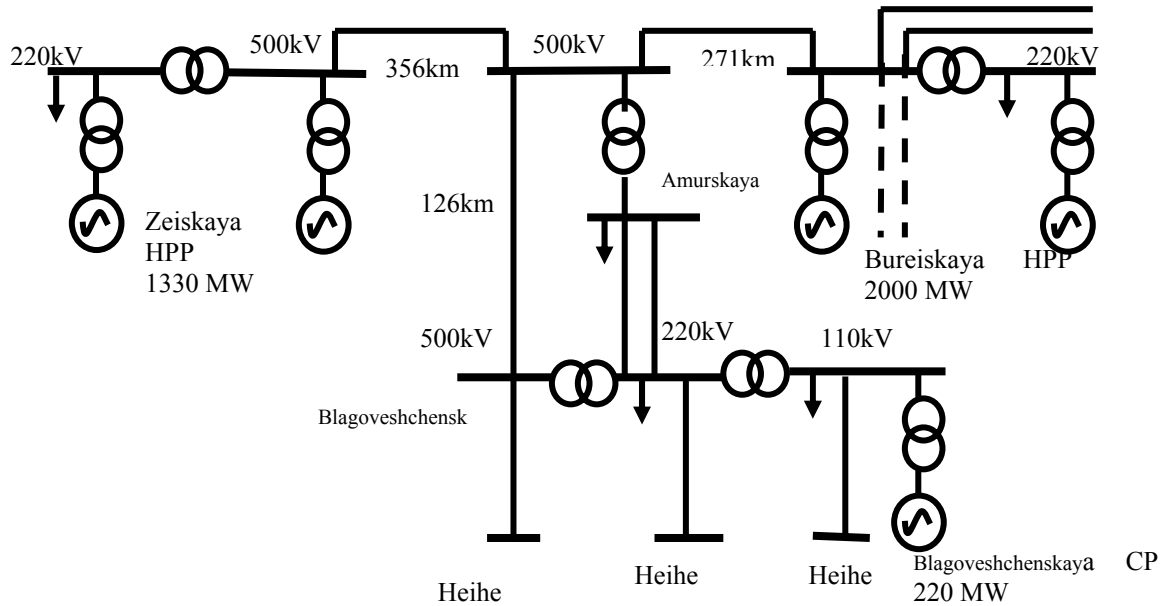


Fig. 1. Scheme of electricity export to China

Besides, the system of frequency and active power control has a crucial impact on synchronous operation of the interconnected power system of East (IPS of East) and the receiving network of China. Construction of even one 500 kV transmission line will guarantee stable synchronous operation of IPS of East and the Chinese power system, since the tie line capacity will make up more than 10% of the power plant capacities in IPS of East. Currently a DC link is under construction in Heihe. As a result the frequency and active power control systems in Russia and China will become independent. Electricity can be exported over two 500 kV transmission lines 60 km long from Bureiskaya HPP substation to the state border (in Fig. 1 they are shown by the dashed lines). This scheme complies with the n-1 criterion. This variant, however, is not considered in the future plans of electricity export.

The agreement on electricity delivery should regulate voltage levels at the boundary nodes and the reactive power values in the intersystem transmission lines. Since electric networks in both China and Russia operate independently, the parties should agree on admissible voltage levels in Heihe and Blagoveshchensk and the volume of reactive power

flow through the interface. Usually this reactive power flow is taken to be minimal. The variant of possible voltage levels is presented in Table 1.

TABLE 1. ADMISSIBLE VOLTAGES OF INTERFACE

Voltage class, kV	500	220	110
Minimum, kV	500	230	115
Maximum, kV	525	240	120

In order to prevent from voltage change by the value that corresponds to response of the on-load tap-changing transformer at the sending and receiving nodes with change in the tie line capacity, voltage should not vary during operation by the value above  $\pm 1\%$ . Taking into account long distances of power transmission by the 500 kV network the contractual value may be taken equal to  $500 \pm 5$  kV.

The voltage levels and the reactive power flow volume can be ensured by construction of a 500 kV substation in Blagoveshchensk, installation of a regulated reactive power source there to maintain voltage levels within the assumed limits. Besides, the necessity arises to consider expediency to install a 500/220 kV autotransformer of 320 MVA capacity at Blagoveshchensk substation to connect 500 and 220 kV networks and four 500

kV circuit breakers to trip two 500 kV transmission lines and the autotransformer for repair.

The main calculated conditions of the 500 kV transmission line are its energization and transportation of maximum power. In the calculated conditions voltage at Zeiskaya and Bureisskaya HPPs is assumed to be maintained at 510 kV level. Voltage at the 500 kV Blagoveshchensk substation can be decreased to the value of 500 kV at minimum capacity by installation of the 142 MVAR reactor. The maximum power transmitted over the 500 kV transmission line is 885 MW at the voltage of 500 kV. If a 100 MVAR reactive power source is installed in Blagoveshchensk, the maximum power transmitted by the 500 kV transmission line will rise up to 1129 MW.

The 220 kV transmission line “Amurskaya substation – Blagoveshchensk” can transmit 171 MW at the reactive power of Blagoveshchenskaya cogeneration plant (CP) up to 100 MVAR and the voltage of 220 kV. Placement of the 50 MVAR reactive power source on the 220 kV side will allow transmission of 229 MW. Installation of the 100 MVAR reactive power source will make it possible to transmit 253 MW.

Thus, the volume of power transmission greatly depends on contractual terms and availability of reactive power sources. It is suggested to take 500 kV voltage as a contractual value; use a 150 MVAR controlled reactor on the 500 kV side for voltage control; install a 50 MVAR capacitor bank for maintaining voltage of two 220 kV transmission lines.

If there is a 500/220 kV autotransformer, then it is expedient to install a reactive power source on the 10 kV side of the 500/220 kV autotransformer. Admissible calculated capacities of transmission lines 110, 220 and 500 kV are estimated at 60, 200 and 700 MW, respectively and the transmitted power – 4,000,000 MWh per year.

If electricity is exported by two 500 kV transmission lines from Bureiskaya HPP, there is no need in reactive power sources be-

cause of small length of transmission lines and only one circuit breaker on each transmission line running to China is used. The transmitted power is estimated to be 7,500,000 MWh. It is possible to implement both variants without commissioning of new capacities in IPS of East.

### III. FREQUENCY AND ACTIVE POWER CONTROL

The installed capacity of power plants in Amur Region is given in Table 2, the planned construction of new capacities is presented in Table 3.

TABLE 2. INSTALLED CAPACITY OF POWER PLANTS IN AMUR REGION, MW

Zeiskaya HPP	1333
Bureiskaya HPP	2000
Blagoveshchenskaya CP	280
Raichikhinskaya TPP	227
Total	3840
Maximum load	1350
Capacity reserve	2500

Even now capacities of power plants exceed the maximum load power almost threefold. Newly-built capacities exceed regional load power. A considerable portion of electricity generated by power plants in Amur Region is transmitted by two 500 kV transmission lines to Khabarovsk.

TABLE 3. CAPACITY OF POWER PLANTS TO BE CONSTRUCTED, MW

Erkovetskaya TPP	1200
Nizhnezeiskaya HPP	400
Nizhnebureiskaya HPP	320
Blagoveshchenskaya CP	100
Raishikhinskaya TPP	200
Total	2220

The power system of Amur Region enters into the IPS of East that includes power plants of Primorye Territory, Khabarovsk Territory, Jewish Autonomous Region, Amur Region, Sakha Republic (Yakutia). The installed capacity of IPS of East is 9.15 GW. In February 2010 the maximum load reached 4980 MW. The maximum historical loads of IPS of East are shown in Table 4.

TABLE 4. HISTORICAL MAXIMUM LOADS OF POWER SYSTEMS IN THE FAR EAST

Power system	Capacity, MW
IPS of East	5 468
Amurskaya	1 350
Primorskaya	2 195
Khabarovskaya	1 828
Yuzhno-Yakutskaya	320

The historical maximum load amounts to 65% of the installed capacity of power plants. Capacity reserve is above 4000 MW.

Forecast of electricity production and consumption in the IPS that was made by the system operator of RAO "EES Rossii" in January 2010 is presented in Table 5. Since no essential changes in electricity production and consumption are forecasted, the IPS of East remains surplus.

TABLE 5. FORECAST OF TOTAL ELECTRICITY PRODUCTION AND CONSUMPTION IN IPS OF EAST FOR THE COMING YEAR AND FIVE YEARS, MILLION KWH

Power interconnection. Power system	Index	Year				
		2010	2011	2012	2013	2014
IPS of East	Consumption	28860	29563	30644	31567	32501
	Production	29058	29893	30945	31701	32830
Amur Region	Consumption	6779	6850	6883	6933	7192
	Production	10202	10372	10374	10381	10581
Primorye Territory	Consumption	11580	12037	12654	13220	13649
	Production	9160	9610	10231	10421	11235
Khabarovsk Territory	Consumption	9091	9246	9666	9966	10190
	Production	7486	7511	7820	8174	8234
Southern Yakutia of Sakha Republic (Yakutia)	Consumption	1410	1430	1440	1448	1471
	Production	2210	2400	2520	2725	2779

Fig. 2 presents daily load curves of the IPS of East for February 1-5, 2010 (working days), February 5 and 6 (weekends), and also winter maximum load on December 22, 2009. Fig. 5 shows daily load curves for summer working days.

The maximum winter load made up 4980 MW, the minimum – 3838 MW. In summer (July 2009) load changes on the working days from 1900 to 2700 MW.

Thus, in the IPS of East there is a sizable surplus of generation capacities, especially in summer time that exceeds 6000 MW. These capacities can be involved in electricity export to China.

Change of frequency in the IPS of East in January 2010 is shown in Fig.6. Frequency deviations as a rule do not exceed  $\pm 50$  mHz. At some time instants frequency deviations reach 90 mHz, and exceed the value established by system operator standard. On Au-

gust 28, 2009, the frequency standard was exceeded by 140 mHz.

In summer a lightning-related trip of the 500 kV transmission line "Amurskaya substation-Blagoveshchensk substation" transmitting 700 MW at a total capacity of power plants in the system of 2600 MW can result in an inadmissible increase of frequency by more than 600 mHz. Therefore, maintaining frequency within admissible limits will require the use of system automatic devices that can disconnect generators, loads, and switch on break resistances at hydropower plants. This situation calls for special studies to preserve a tie line with China through the remaining 110/220 kV transmission lines and a tie line with Yakutia through the 200 kV transmission line. Correspondingly, China should have primary capacity reserves of no less than 700 MW. This condition is met in China since the capacity of all units at thermal power plants is 600 MW and higher. Import from Russia is equated with disconnection of one unit at

thermal power plant. Such reliability, being admissible for China, is problematic for Russia. Tripping of the 500 kV transmission line “Zeiskaya HPP – Amurskaya substation” transmitting 500 kW is also a severe disturbance. An export 500 kV transmission line will make it possible to avoid emergency disconnection of loads in this situation in Khabarovsk power system, since the transmission lines will be unloaded.

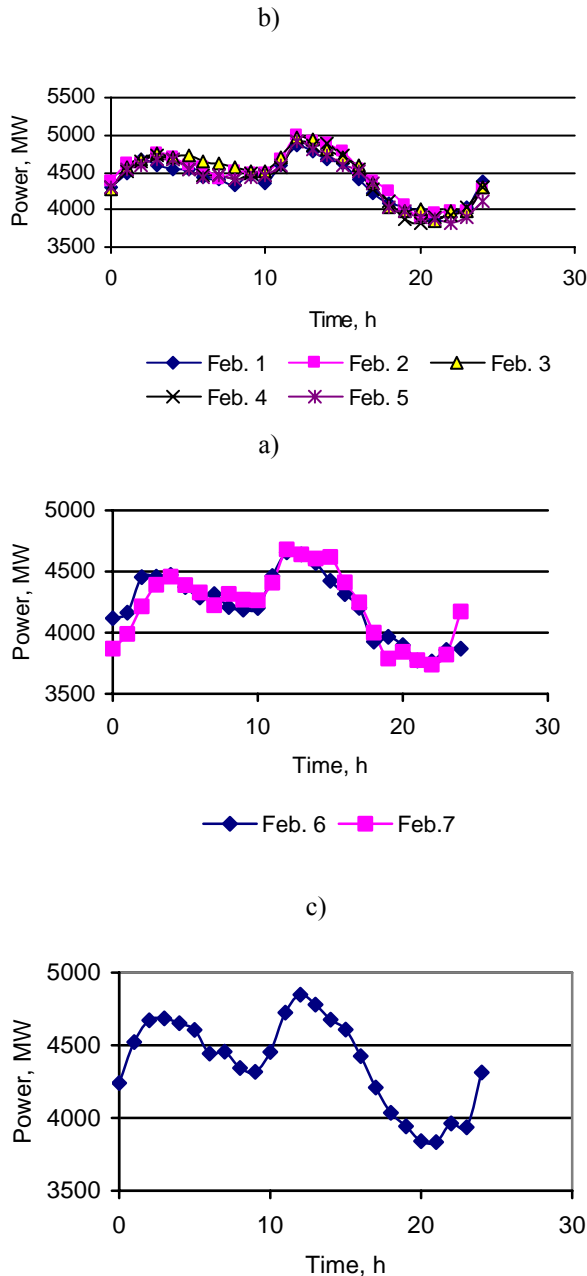


Fig.2. Consumed power in IPS of East: a) on working days on February 1-5, 2010; b) on Saturday and Sunday of February 6-7; c) at winter load maximum on December 22, 2009.

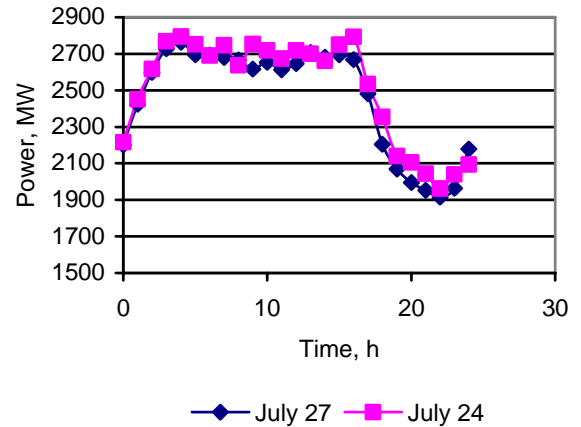


Fig.5. Consumed power in the IPS of East on July 24 and 27, 2009

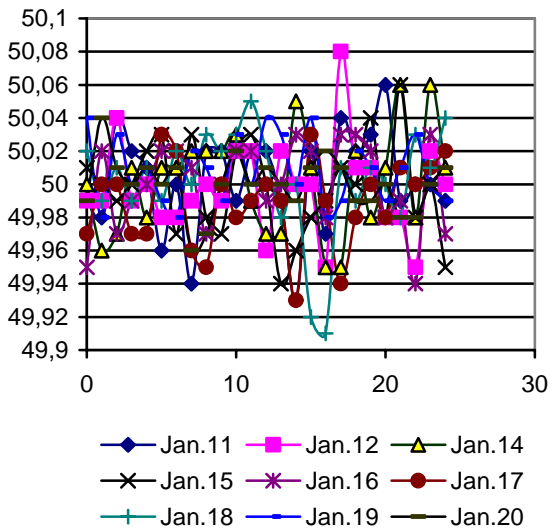


Fig.6. Change of frequency in the IPS of East in January 2010.

#### IV. ECONOMIC EFFICIENCY OF ELECTRICITY EXPORT TO CHINA

The project for increase of electricity export from Russia to China can be considered as an example of major project in the field of power engineering in the East of Russia. According to the project the Russian company “VEK” should construct a 500 kV transmission line from Amurskaya substation to the Russia-China border. The partner on behalf of China, the State Grid Corporation of China, is already constructing a 500 kV transmission line from the Russia-China border via DC link in the area near Heihe to Harbin. At the first stage of the project China will receive 3.6-4.5

billion kWh annually which corresponds to power export by the 220/500 kV transmission lines with a capacity of 900 MW with the number of capacity utilization hours equal to 4000-5000. Capital investments in the construction of the 500 kV transmission line are estimated at 3302 million rub. The amount will be obtained by issuing shares to the amount of 743 million rub and taking the credit in the amount of 2558 million rub. The costs of electricity transmission through this transmission line, considering repayment of bank credit during 10 years at an interest rate of 5%, is estimated at 220 Rub/MWh, without VAT. In the coming years the crediting rate may rise by 4% due to increase of the interbank offered rate. Change in the interbank offered rate from 2001 to 2010 is shown in Fig.7. In this case transmission costs will increase up to 256 Rub/ KWh.

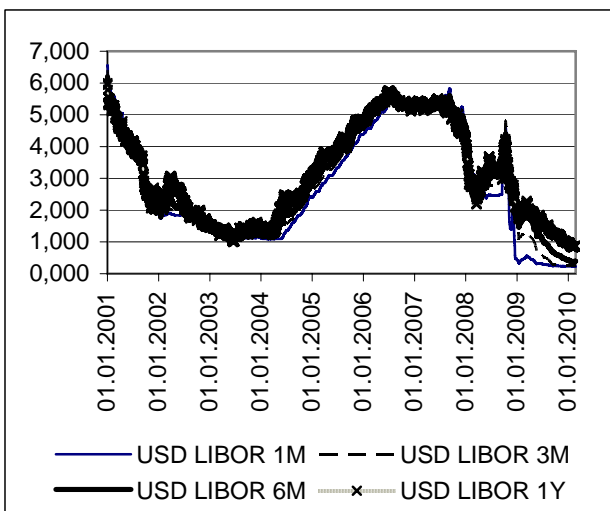


Fig.7. International interbank offered rate for the period from 1 month to 1 year.

China can buy electricity at a price no higher than 0.04 \$/kWh which corresponds to 1200 Rub/MWh.

Electricity prices in the Far-Eastern Federal District [4] are shown in Table 6.

Two-part tariffs for consumers connected to the networks of 110 kV and higher are presented in Table 7. Purchase price corresponds to the selling price including VAT

TABLE 6. ELECTRICITY PRICES IN THE FAR-EASTERN FEDERAL DISTRICT

Electricity	Price, Rub/MWh
generated at power plants of the Far East	550
Supplied to consumers	2292
purchased	3216
purchased in the wholesale market	2856
purchased in the wholesale market at regulated tariffs	2856

TABLE 7. A TWO-PART TARIFF FOR LEGAL PERSONS CONNECTED TO THE NETWORKS OF 110 KV AND HIGHER WITHOUT VAT FOR AMUR REGION

Capacity, Rub/MW	1147921
including:	
Power plants	448906
Network maintenance	699015
Electric energy, Rub/MWh	495.4
including:	
Power plants	345
Transmission maintenance, losses	154

Network maintenance tariff exceeds electricity production tariff. The wholesale electricity price is 0.0952 \$/kWh.

In 2009 739 million kWh was exported by the 220/110 kV transmission line from Blagoveshchensk to Heihe to the amount of \$29.09 million (0.039 \$/kWh). For 2010 the contract for supply of 1 000000 MWh is concluded to the amount of \$40 million (0.04\$/kWh or 1200 Rub/MWh). The indicated supplies correspond to transmission of 200 MW during 5000 h.

The selling price is higher than the price of electricity at power plants in the Far East but much lower than the purchase price in the wholesale market (2856 Rub/MWh).

Here is a comment on the economic aspect of electricity export to China that was made by director general of the JSC "VEK" [5], "We purchase surplus electricity in the Far-East in the wholesale market and sell it at the price corresponding to the wholesale market level in China and acceptable for our partner. We do not sell electricity at the prices below those existing in the Russian wholesale market. As to the export revenues they are distributed

among all participants involved, i.e. power sales, network and generation companies. The funds received from selling electricity to China can be used by the companies only for the purposes of generation and network expansion. The wish of our Chinese partners to purchase electricity at a price as low as possible is as natural as our wish not to sell at a loss. Up to date we have agreed to “bind” the cost of 1 kWh to the prices in the wholesale electricity markets of the RF and China in a certain year of supply.

Current rules of the wholesale electricity market in the IPS of East do not allow us even to payback our costs of export-related activities. At the same time the other participants of the market, first of all the Far-Eastern company which is involved, according to the current rules, in all electricity transactions in the IPS of East gains considerable economic benefit from export. While we at best get the so called “zero income”.

It should be noted that the electricity cost at power plants is below 2 cents. Transmission and distribution component is the largest in the tariff. Therefore, export is justified if to cease the use of the Amurenergo networks and construct own export transmission lines. Construction of two circuits of an export 500 kV transmission line from Bureiskaya HPP to the state border, 60 km long, will make it possible to purchase electricity directly from the JSC “Rosgidro” and export nearly 5000000 MWh by own transmission line. The transmission line will provide stable synchronous operation of power systems and fuller loading of power plants in the Far East during summer. It will also help maintain frequency more accurately. There will be no need to disconnect consumers in the case of trip of the 500 kV transmission line from Zeiskaya HPP to Bureiskaya HPP.

In 2002-2008 the electric power industry of China saw considerable technical and economic changes. The country made a technical breakthrough in construction of factories for manufacturing electric equipment and development of construction and design organizations. In order to decrease the cost of power

plants a flow-line production and construction of thermal power plants with 600 MW units was organized. In 2009 the capacities of 100 GW were put into operation. The enterprises in Harbin alone can put in operation thermal power plants with a capacity up to 30 GW annually. In 2008 surplus capacities in power plant construction and electric equipment production appeared in China. In June 2008 the government of China made a decision to support construction of power plants in other countries by granting preferential loans with a state guarantee to construction companies and maintain investments in energy facilities abroad. The joint Russian-Chinese company “RK Energostroi” Ltd was created to construct energy facilities by Chinese companies in Russia at the expense of loans granted by the bank of China. Currently the electricity cost price in China is below 0.03\$/kWh, the wholesale price is 0.04 \$/kWh. There are four generation companies supplying power in China at fixed prices. Each company supplies no more than 29% of electricity consumed in every province. This leads to the necessity to improve the technology of electricity production and to the shutdown of obsolete capacities.

The cost of power plant and transmission line construction in China is considerably lower than that in the Far East. The cost of coal units in Russia is estimated at \$2500, in Europe - at \$1800 and in China - at \$720 [6]. Conclusion of a turnkey contract with the company “RK Energostroi” Ltd for construction of power plants and transmission lines by Chinese companies at the expense of China’s credit is tempting. Under the existing project the cost of Erkovetskaya 1200 MW TPP is estimated at 33300 million rub. Electricity cost at a credit repayment period of 10 years and bank rate of 5% will be above 4.7 cent, i.e. it will not be competitive in the wholesale market in China (4 cents). However, the cost of electricity at this plant can be decreased to 2 cents by reducing the cost of construction and giving up the use of distribution network services.

## V. CONCLUSIONS

1. There is a considerable reserve of generation capacities in the Far East that can be used for electricity export.
2. Construction of 500 kV transmission lines from Amurskaya substation to the state border and from Bureiskaya HPP to the state border makes it possible to sell surplus power generated by power plants in the power systems of the Far East.
3. Transfer capabilities of export transmission lines depend greatly on systems of voltage and reactive power control.
4. Electricity export from Amurskaya substation through one-circuit 500 kV transmission line does not meet the reliability criterion n-1 and in the case of the transmission line tripping the automatic emergency control systems should be used.
5. Technically and economically electricity export is efficient through two circuits of the 500 kV transmission line from Bureiskaya HPP to the state border. Since the length of the transmission line is shorter than 60 km its operation can be regulated by Bureiskaya HPP.
6. Electricity export is admissible if electricity export tariff is no lower than the tariffs for the enterprises in the Far East.
7. Electricity tariffs in the Far East are dominated by transmission and distribution component. Therefore, special export transmission lines should be used for electricity export. This calls for a special decision of the Government.
8. China achieved considerable progress in production and construction of energy facilities and in decrease of their costs. There is a considerable reserve for construction of energy facilities. Creation of a joint venture dealing with construction of energy facilities

in Russia and its preferential financing by the bank of China makes involvement of the company “RK Energostroi” Ltd attractive for turnkey construction of energy facilities in the Far East.

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