From the volume „*Complex electricity markets*", Edition: „The European power supply industry", Technical University of Lodz, May 2006

Complex electricity markets

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1. Introduction

The sustainable development requires the coordinated optimization of the energy resources, the reduction of emissions and the development of renewables energy sources. There are several ways that can be applied to reach this goal. The most preferable methods are various market mechanisms as such mechanisms are the most effective.

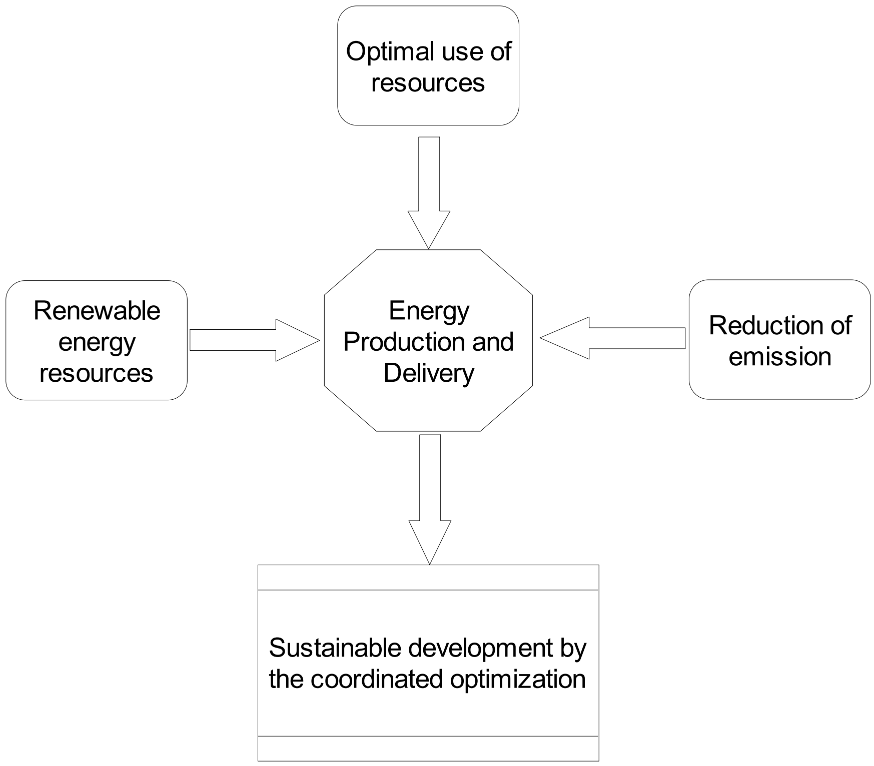

Fig. 1 Sustainable development

2. Certificates and allowances

The certificates of the electricity origin and allowances to produce some limited amount of emissions are the most common market mechanisms applied in the European countries.

Currently the green certificates have been introduced in several countries as the market system supporting the development of renewable energy resources. White certificates, which relate to various forms of energy conservation have been tested in Italy and a similar system without the direct form of certificates has been introduced in England.

It is quite obvious that the supporting scheme for the production of electricity in cogeneration with heat can have a form of the "red certificates" with the similar rules as the green certificates. The amendments to the Polish Energy Law planned for 2006 aim at the laying down the provisions determining the red certificates as the supporting scheme for cogeneration. Currently there are three certificates schemes: green, red and white certificates which can be introduced in member state countries.

The emission reduction leads to the limited quotas of gas emission assigned to the particular countries, which consequently split the quotas obtained among industries in a national level and between companies of these industries. The first scheme for CO2 allowance trading was introduced in 2005. The trading is not very vigorous due to the lack of experience and uncertainty relating to the future electricity prices.

It seems quite natural that the limitation of SO2 emissions can be associated with the trading system of SO2 allowances. In some countries such as Poland the discussion takes place on the development of a SO2 allowance trading scheme. The reduction of NOx emissions can also be associated with the allowance trading scheme.

Figure 2 shows the relations between electricity producers and energy traders and users. The main relation associated with the energy trade is the energy balancing which is important service provided by the TSO or the DSO. The energy streams are associated with various certificate and allowance trading schemes.

The mutual relation of allowance trading and electricity production is still not adequately recognized and analyzed. Power stations having allowance for CO2 emission can sell these allowances restraining from the electricity production if they forecast low electricity prices and high prices for allowances. The current price of CO2 allowance is about 25Euro per ton, which is larger than the fixed cost of many power generation units. This leads to the temptation to sell allowances instead electricity production.

On the other hand some power generation units are must run units which should be available to maintain technical requirements of the transmission system operation. When such generating units select the allowance trading option the TSO can have problems when contracting must run services. Not only availability of such units become a problem to solve but also price of must run services should take into account possible income of power stations from selling CO2 allowances on the market. Many forecasts indicate the CO2 allowance price on the level of 40Euro per tone before 2008. This will lead to the higher cost of transmission services.

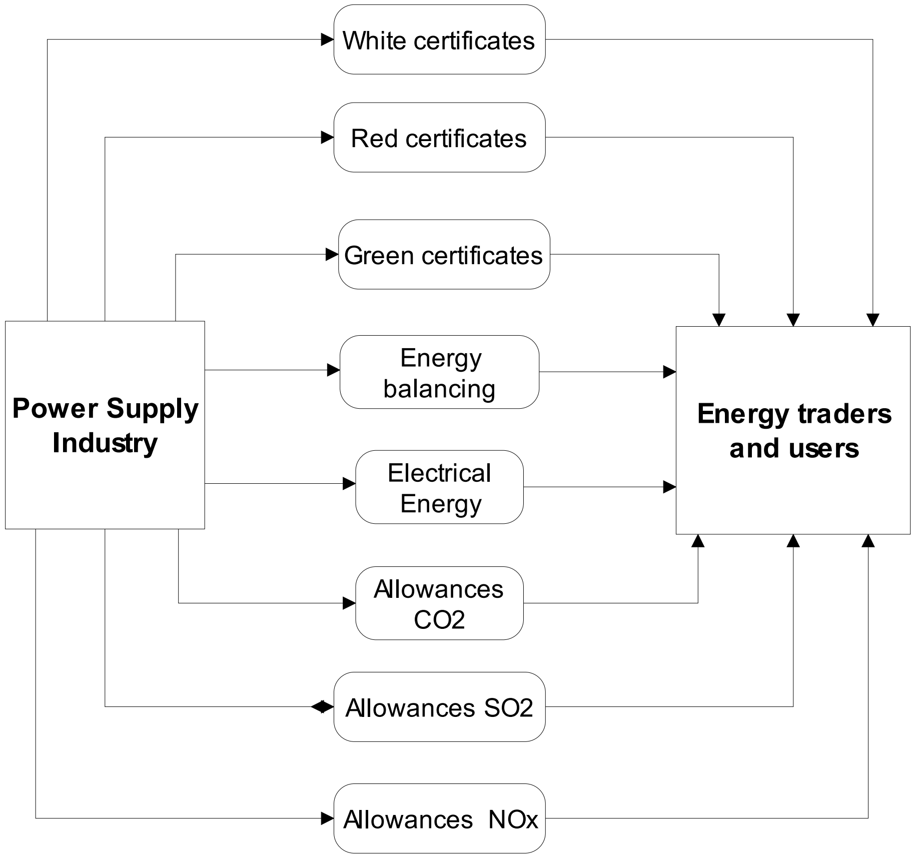

Fig. 2 Impact of various mechanisms

The similar analysis can be carried out in the relation of SO2 allowances when such a system is introduced. If such allowances are in place generating units equipped with installation to reduce SO2 emission will be in favor leading to larger load of electricity generation to such units. Other units with larger SO2 emission will have to reduce production or invest in the installation to reduce SO2. However if generating units are old and overused it is not worth investing only in the installation to reduce SO2 emission. Power stations with such generating units have choice to rebuild generating units which is very expensive process or restrain from the electricity production. If such units are must run units the analysis carried out for CO2 and impact of SO2 allowance trade applies.

There are several direct and indirect relations between electricity trade and balancing services and various schemes of certificate and allowance trading. The design of electricity market, in particular, the day ahead and the intra day balancing market requires more detailed consideration of the impact which allowance and certificate trading can have on the behaviour of market participants.

3. Complex electricity market

Energy markets and associated markets should be analyzed and designed taking into account the mutual relations between various schemes. Figure 3 depicts the energy market scheme that should be considered if the liberalization of the energy industry is introduced. The fuel market is the important component in the entire scheme. In Europe, this market requires further diversification and the introduction of more market rules in gas and coal supply. Liberalization of gas supply industry and railways transport are key issues impacting the fuel market performance.

The electricity market should be associated with balancing markets both the day ahead and the intra day market and the power exchange with the adequate liquidity providing the reference price for middle term and long term transactions. Certificate and allowance markets can be constructed as bilateral markets with the support of the power exchange as the additional place for certificate and allowance trading. The important question is: which entity should keep the register and verifies the obligation to purchase certificate or clearing the balance between amount of allowance and real gas emissions. There are several solutions possible to implement designing the trade schemes for emission and allowances.

There are four main markets which can be managed by the TSO. They include: the balancing market, the Ancillary Services markets, the generating capacity market and the transmission capacity market. The Ancillary Services market usually includes secondary and tertiary reserve. Such markets have been implemented in several countries. All four markets should be managed by the TSO, which should also introduce markets for transmission capacity crossborder lines – Fig. 3.

The effective operation of the complex electricity market requires the careful coordination of market rules as all segments of the complex electricity market can have impact on each other.

4. Generating capacity

Generating capacity market can address the problem of incentives for new generating capacity investment. Directive EC/54/2003 indicates two main procedures of investment in generating capacity. The first one is called an authorization procedure and has been adopted by all European countries. The main rule is that any entity can invest in generating capacity providing it satisfies the national regulations relating to environmental issues and ensures safe technical operation of the plants.

However the authorization procedure cannot provide the expected outcomes when there are not economic price signals for investment. In such a case the directive indicates the second procedure called a tendering procedure in which a regulatory body in a given country can call for tenders to construct new generating plants. However in the presence of low electricity prices, what is common now, the regulatory body calling for tenders should indicate some incentives to enter such a procedure. On the other hand any incentive can be treated as state aids and results in discriminatory approach to old investors.

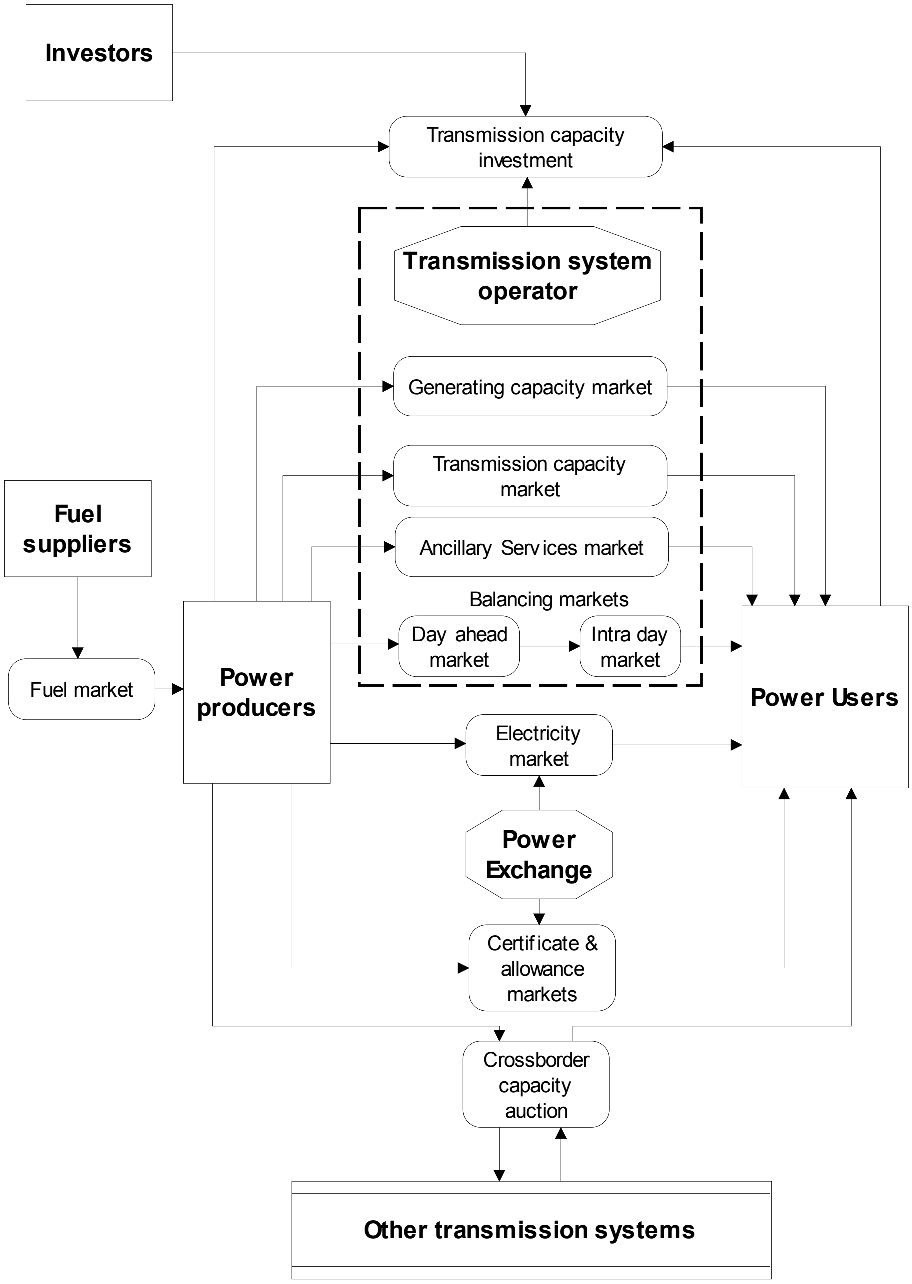

Fig. 3 Complex electricity markets

The better outcomes can be obtained by the introduction of any market form of payment for generating capacity. Of many forms of capacity payment the obligation imposed on loads seems to be one of the best and simple solutions. All energy traders in a wholesale market should purchase generating capacity in the amount relating to their maximum demand. Taking into account some level of power reserve required, the amount of generating capacity that should be purchase is larger about 15-20% than maximum power demand. The contracts for generating capacity should be presented to the TSO for verification. The TSO should also organize some form of a generating capacity balancing market to allow the purchase of generating capacity by energy traders which do not serve the loads on a regular basis.

5. Transmission capacity

In many discussions transmission capacity market is seen as a market when capacity of transmission lines connecting some regions, called sometime interconnectors or countries are traded in various forms for example on a capacity auction. However there are power systems in which constraints do not result from a capacity of interconnectors but from levels of voltages and the reliability criterion N-1. In such a case transmission constraints can be formulated as nodal constraints in several categories. The constraints can relate as well to start up of generating units.

For example in the Polish transmission system the network and system operation constraints are formulated in terms of seven main categories such as:

- ***MaxP*** – maximum power injected into the node or taken out of the node
- ***MinP*** – minimum power injected into the node or taken out of the node
- ***MaxJ*** – maximum number of generating units working in the node
- ***MinJ*** – minimum number of generating units working in the node
- ***MaxSt*** – maximum number of starting up, in the same time, generating units connected to the node
- ***MaxUp*** – maximum increase rate (ramp) of power injected or taken out of the node
- ***MaxDown*** – maximum decrease rate of power injected to or taken out of the node

The combination of the above listed categories permits a representation of any network constraints.

If a number of nodal constraints is not large the TSO can enter various contract to ensure the adequate generating capacity in a specific node and operational availability. However when operation of a power system requires, this happens in the Polish power system, a large number of operating units to be available the costs of such contracts, which is usually paid by the transmission charges, becomes very high leading to the increase of transmission and distribution charges. In such system it is better to arrange the trade of constraints imposing on wholesale market participants the obligation to purchase some amount of constraints.

5. Markets for generation capacity and nodal constraints

The proposal of the introduction of the market for generation capacity and nodal constraints is based on the generation capacity markets which operate in some states of the US , where Load Serving Entities are obliged to purchase some amount of generating capacity. However the proposal presented in this chapter is more complex combining in one market both generating capacity and constraint trade.

5.1. Energy trading and balancing

A typical wholesale electricity market is shown in Fig. 4. Power producers sell electrical energy to wholesale traders and larger users. Wholesale traders supply end user with the electricity purchase in a various form of bilateral contracts. Both Power producers and trades submit information on the trade to the TSO. Additionally power stations and in some market electricity users can submit balancing bids to the TSO, which uses these bids for balancing.

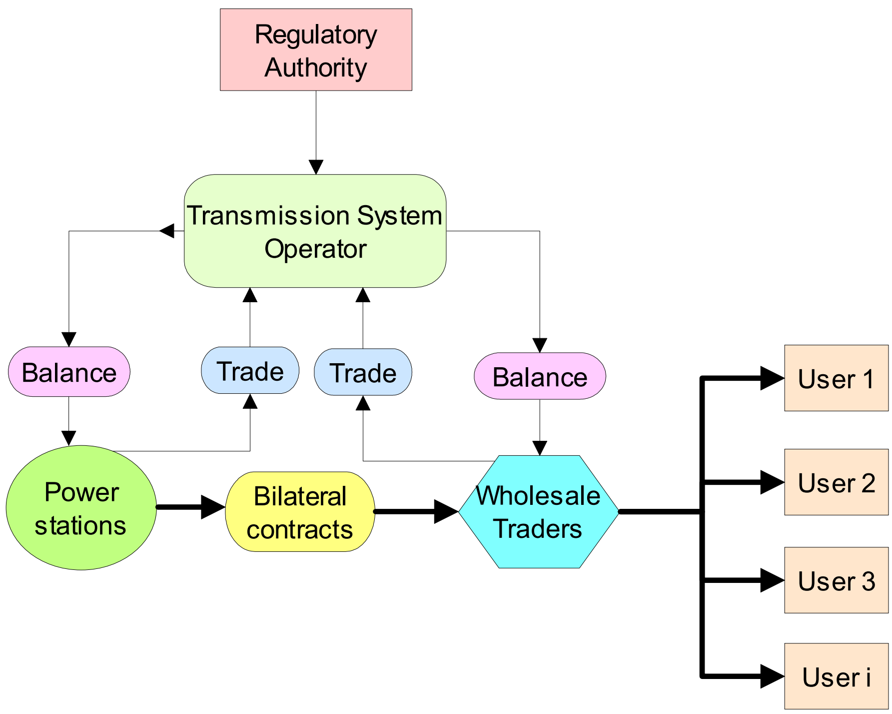

Fig. 4 Energy trade and balancing

5.2 Nodal constraints

In the Polish power system the TSO purchases energy from generating units which are required to operate due to the technical condition of the transmission network. The nodes and a number of units which operates as must run are published every year the TSO as the annual contingency plan. This plan is updated monthly and two days before the system operation. Small number of these nodal constraints results from the outages and lines maintenance, however most of them results from the structure of transmission network and reliability conditions and are fixed.

When power producers inform the TSO about the electricity trade and they do not locate the electricity sold to the must run generating units the TSO preparing schedule calls for operation of such generating units buying electricity from this units and to keep balance selling electricity to other units which have to reduce generation to obtain the balance in power system production and consumption. Such operation carried out by the TSO in the balancing market costs about 15Euro per 1MWh and is covered by the transmission charges and it is transfer to final energy users by distribution chargers – Fig. 5.

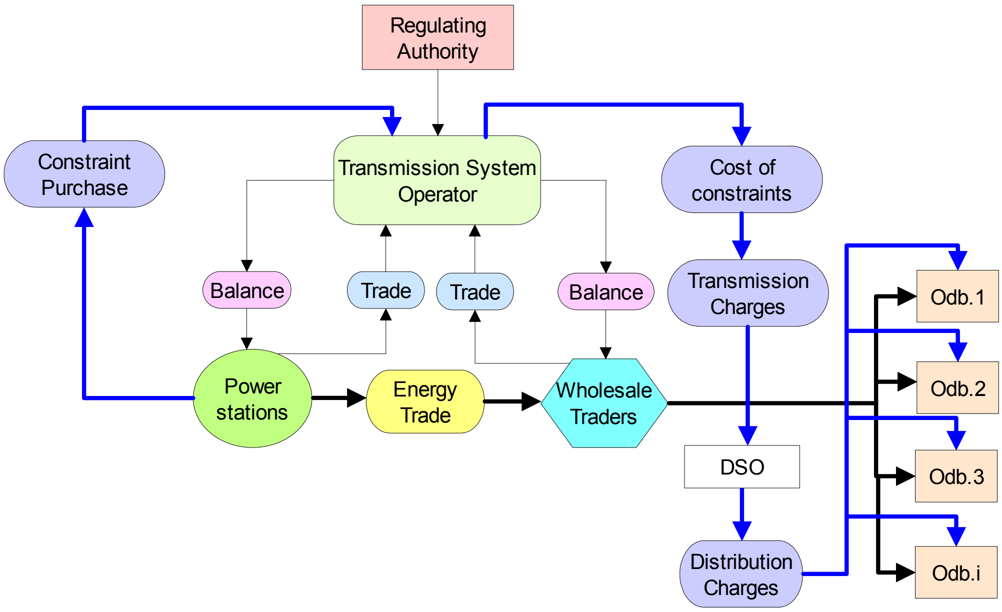

Fig. 5 Current system of energy trade and transferring cost of constraints

5.3 Trading generating capacity

The trade of generating capacity can be introduced by imposing on wholesale traders and large loads connected directly to the transmission system the obligation to purchase some amount of generating capacity in relation to their maximum demand taking into account some level of power reserve usually about 15-20%.

After the trade of generating capacities both parties once per year should submit to the TSO the information on the amount of generating capacity purchased and sold – Fig. 6. Power stations can submit balancing bids offering spare generating capacity to the TSO. Such generating capacity balancing bids can be used to sell capacity to the traders when maximum demand is larger than the forecast or enabling the purchase capacity by traders carrying out accidental transitions.

The system of generating capacity trading allows for enabling investments in generating capacity as contracts for such capacities can be arranged as middle and long term contracts reducing the risk of investment.

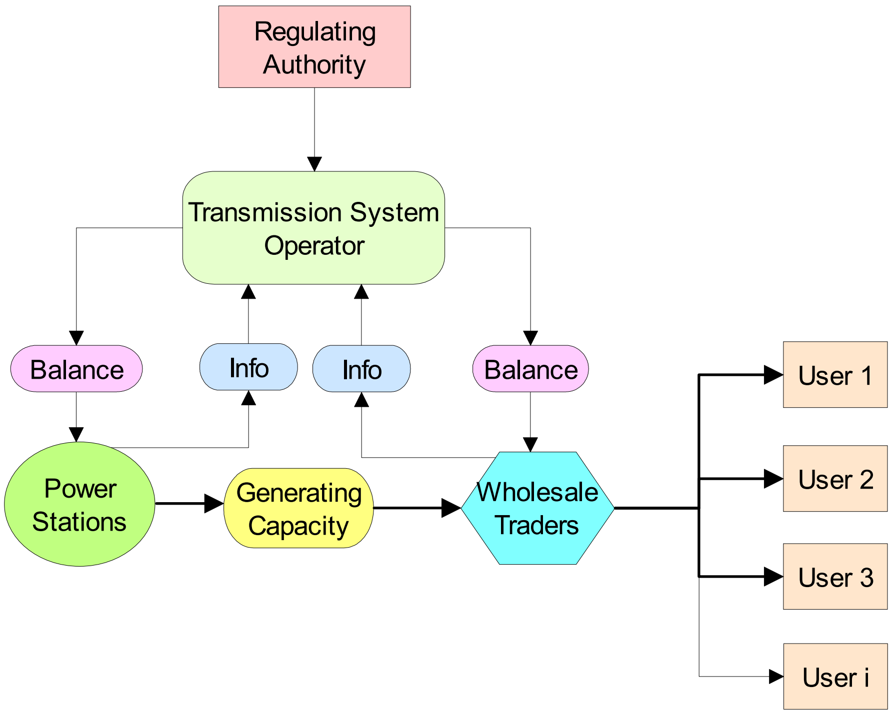

Fig. 6 Proposed system of generating capacity trade

5.4 Trading nodal constraints

As discussed in section 5.2 most of the nodal constraints results from the network configuration and technical operating conditions which are fixed for year to year. It is possible to define "fixed" nodal constraints and calculate such constraints in terms of MW and percentage to the maximum demand. In practice a market participates will be obliged to purchased flat band of the electricity – Fig. 7.

The system of constraint trade can be very similar to the system of generating capacity trade – Fig. 8. Power stations and wholesale market trades are entering bilateral contracts for constraint electricity informing the TSO about the amount of electricity purchased and sold. The constraints which are not purchased in the bilateral contracts can be offered to the TSO which can use such bids for balancing the need for constraint energy.

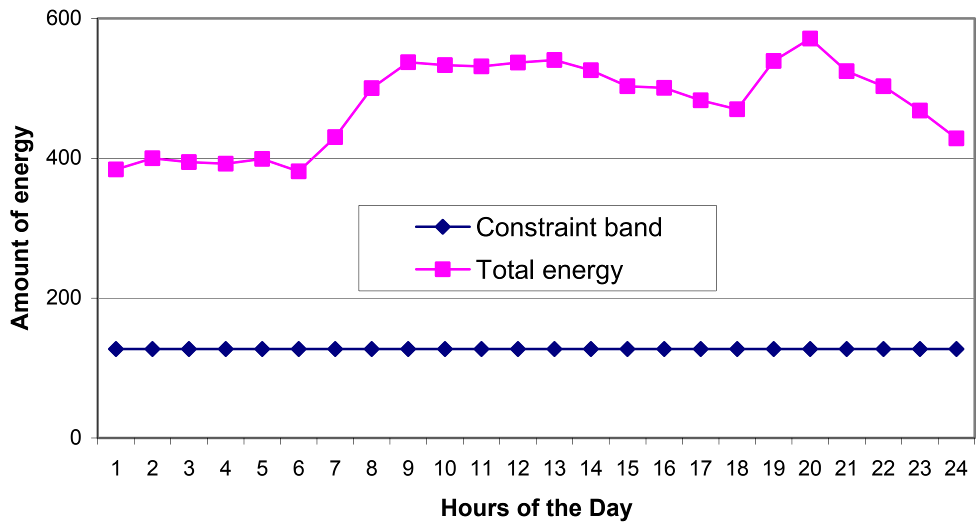

Fig. 7 Daily electricity profile and the band of constraint energy assigned

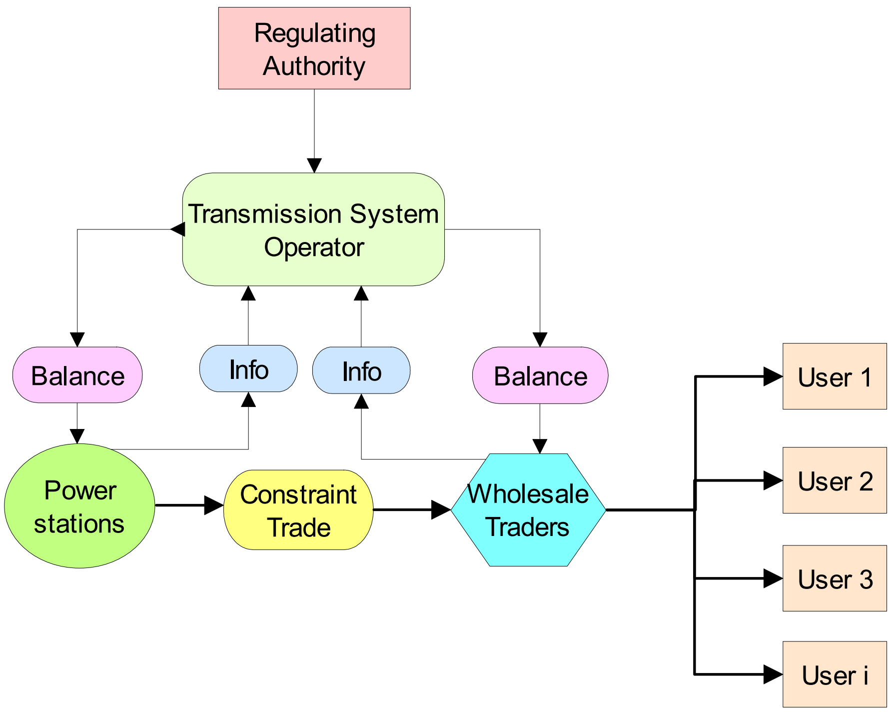

Fig. 8 Proposed system of constraint trade

5.5 Wholesale market trade

If a proposed system is introduced the trade in the wholesale electricity market will be the combination of the electrical energy trade and the trade of some technical features required for the operation of power systems – Fig. 9. The electricity trades is carried out as bilateral contracts with the balancing in the day ahead and the intra day market. Constraints trade is also in a form of bilateral contract with annual balancing. Similarly generating capacity trade is carried our as bilateral contracts with annual balancing.

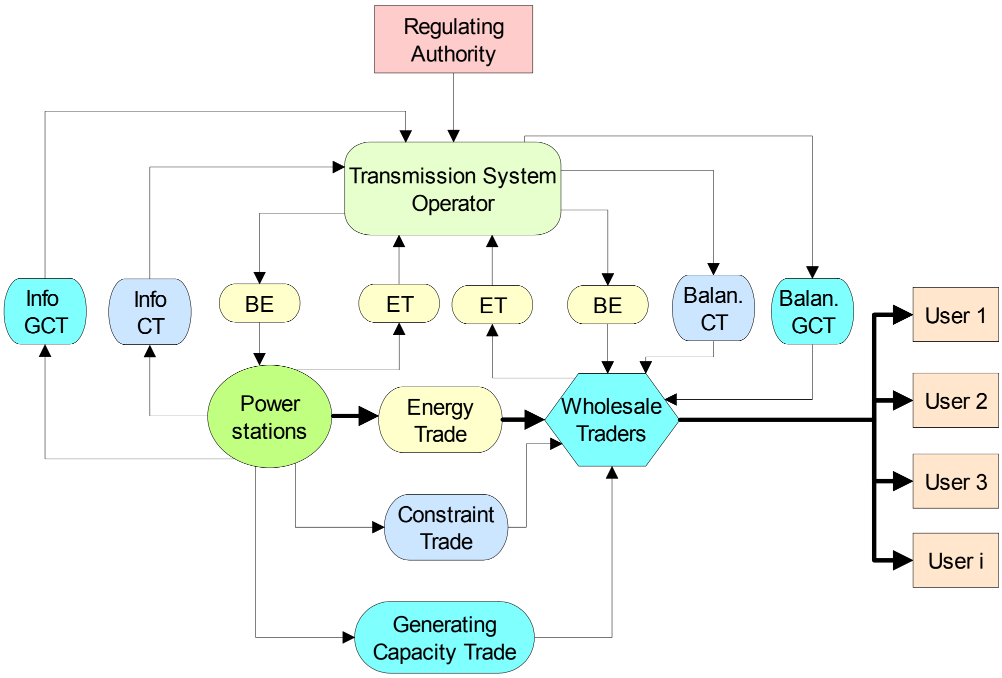

Fig. 9 New system of constraint and generating capacity trade

6. Example of constraint market

The example of the constraint market is given taking into consideration three power stations having generation units connected to the power system in two nodes – Table 1. The TSO has determined that in the node A1 one unit is require to operate, in the node B1 three units, in the node B2 one unit, in the node C1 one unit and in the node C2 two generating units are required for the adequate system operation.

Assuming that there are four electricity traders operating in the wholesale market and taking into account their demand profiles the TSO determines the amount of constraints to be purchased by them – Table 2.

Table 3 shows the electricity and constraint trade without a need for balancing. For example Trader 1 has purchase totally 810MW of which two units A14 and B22 can be counted as constraint units and included into the trader’s obligation to purchase the constraints.

Fig. 4 demonstrates the case when electric power from one generating units which is on the constraint list has not been purchased by any traders. In the TSO calculation this unbalance appears in the node B1 as the negative value of 120MW. To balance the constraint trade the TSO takes action and buys power from units B11 as the cheapest one in node B1 and sell the same amount of energy to the unit B23 as the most expensive in the entire market – Table 5. In the case of the Polish power system such operation would cost about 1500Euro per hour and such cost will be allocated to Trader 3 as it has negative balance in constraint trade.

It is also possible a case when despite the unbalance in particular traders the TSO does not need to balance the constraint trade – Table 6. Trader 3 has negative balance but Trader 4 has positive balance because for some reasons, for example attractive price he has purchased more energy from constraint units that its obligation making the nodal balance positive.

Table 1 Power stations and generating units

Power Station	Node	Unit	Pmin	Pmax	SMINJ	Constraint Pmin	Share %
A	**A1**	A11	120	200	**1**		
		A12	120	200		120	
		A13	120	200			
		A14	120	200			
	A2	A21	260	370	**0**		
		A22	260	370			
B	**B1**	B11	120	200	**3**		
		B12	120	200		360	
		B13	120	200			
		B14	120	200			
	B2	B21	120	200	**1**		
		B22	120	200		120	
		B23	120	220			
C	**C1**	C11	270	360	**1**		
		C12	270	360		270	
		C13	270	360			
	C2	C21	120	220	**2**		
		C22	120	220		240	
		C23	120	220			
		Sum	3010	4700		1110	
						Constraints	30

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Table 2 Constrains assigned to traders

Trader	Constraints assigned [MW]
1	240
2	270
3	360
4	240

Table 3 Energy and constraint trade

Gen unit	Trader 1 Energy	Trader 1 Constraints	Trader 2 Energy	Trader 2 Constraints	Trader 3 Energy	Trader 3 Constraints	Trader 4 Energy	Trader 4 Constraints	Node balance
A11			160				40		
A12									**340**
A13							180		
A14	140	***120***							
A21					370				**740**
A22			200		170				
B11									
B12					120	***120***			
B13					120	***120***			**0**
B14					120	***120***			
B21							170		
B22	170	***120***							**570**
B23			150		200				
C11	150						210		
C12			350	***270***					**440**
C13									
C21			50				120	***120***	
C22	350						120	***120***	**520**
C23					120				
Sum	810	240	910	270	1220	360	840	240	
	Constraints	240		270		360		240	
	%	29,6		29,7		29,5		28,6	

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Table 4 Unbalance in constraint trade

Gen unit	Trader 1 Energy	Trader 1 Constraints	Trader 2 Energy	Trader 2 Constraints	Trader 3 Energy	Trader 3 Constraints	Trader 4 Energy	Trader 4 Constraints	Node balance
A11			160				40		
A12					*120*				**340**
A13							180		
A14	140	***120***							
A21					370				**740**
A22			200		170				
B11									
B12					120	***120***			***-120***
B13					120	***120***			
B14						***-120***			
B21							170		**570**
B22	170	***120***							
B23			150		200				
C11	150						210		
C12			350	***270***					**440**
C13									
C21			50				120	***120***	
C22	350						120	***120***	**520**
C23					120				
Sum	810	240	910	270	1220	240	840	240	
	Constraint	240		270		360		240	
	Difference	0,0		0,0		-120,0		0,0	

Table 5 Balancing the constraint trade by the TSO

Gen unit	Trader 1 Energy	Trader 1 Const	Trader 2 Energy	Trader 2 Const	Trader 3 Energy	Trade r 3 Const	Trader 4 Energy	Trader 4 Const	Node balance	Buy [MW]	Sell [MW]	Cost
A11			160				40					
A12					120				**340**			
A13							180					
A14	140	***120***										
A21					370				**740**			
A22			200		170							
B11					120	120				120		3780
B12					120	***120***			**0**			
B13					120	***120***						
B14												
B21							170		**570**			
B22	170	***120***										
B23			150		200							
C11	150						210		**440**			
C12			350	***270***								
C13												
C21			50				120	***120***	**400**			
C22	350						120	***120***				
C23					0						-120	-2640
Sum	810	240	910	270	1220	240	840	240				1500
	Const	240		270		360		240				
	Differ	0,0		0,0		-120,0		0,0				

Table 6 The unbalance in traders without a need for the TSO action

Gen unit	Trader 1 Energy	Trader 1 Constraints	Trader 2 Energy	Trader 2 Constraints	Trader 3 Energy	Trader 3 Constraints	Trader 4 Energy	Trader 4 Constraints	Node balance
A11			160				40		
A12					120				**340**
A13									
A14	140	***120***							
A21					370				**740**
A22			200		170				
B11							180		
B12					120	***120***			**60**
B13					120	***120***			
B14									
B21							170		
B22	170	***120***							**570**
B23			150		200				
C11	150						210		
C12			350	***270***					**440**
C13									
C21			50				120	***120***	
C22	350						120	***120***	**520**
C23					120				
Sum	810	240	910	270	1220	240	840	240	
	Constraints	240		270		360		240	
	Difference	0		0		-120		120	

7. Need for coordinated optimization

A fast growing market relating to various aspects of electricity and technical operation of the power systems require more coordination and research to analyze the possible impact of particular markets on each other. Fig. 10 shows the most important steps which include the analysis of various certificate trade and the analysis of emission reduction mechanism. The next step should be the research on mutual impact of trading mechanism including certificate and emission allowances trade. The next steps should include the analysis of optimal resources allocation and as the final product the coordinated optimization of electricity production , delivery and various supporting schemes.

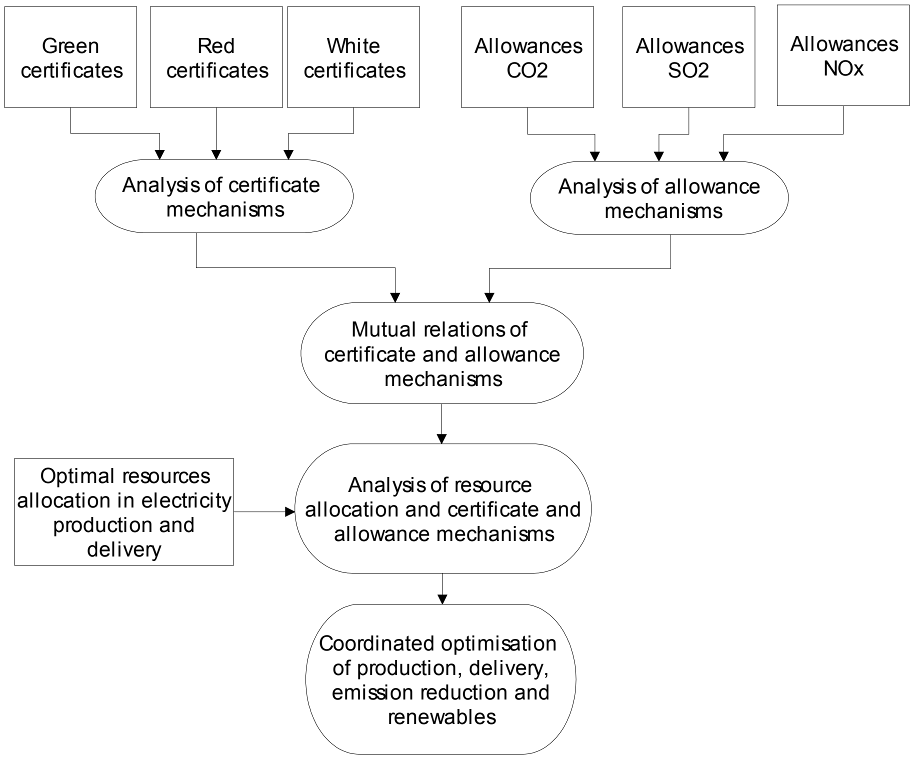

Fig. 10 Coordinated optimization