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(54) AUCTIONING METHOD AND SYSTEM FOR ELECTRICITY MARKET COMMODITIES

(57) The invention relates to a method of an electricity exchange system_comprising a set of nodes of a physical electricity network, a set of transmission lines interconnecting said network nodes, wherein line energy physical flow is constrained by an upper limit, where energy physical flow is defined as a linear function of nodal energy injections, whereas nodal energy injection is defined as energy injected minus energy absorbed in the respective node, further comprising a group of nodes in arbitrary number of electricity exchange zones, a set of energy exchanges transacted between interconnected electricity exchange zones, a set of supply orders for energy injection in each node, and a set of demand orders for energy absorption in each node; the method is remarkable in that it comprises the steps of setting an electricity exchange zone clearing signal for each electricity exchange zone, establishing cleared supply energy volumes in each node with supply order thresholds ≤ the corresponding electricity exchange zone clearing signal, establishing cleared demand energy volumes in each node with demand order thresholds ≥ the corresponding electricity exchange zone clearing signal, setting transmission line flows ≤ the respective flow limit, establishing energy exchange volumes between electricity exchange zones with direction from an electricity exchange zone with a lower clearing signal to an electricity exchange zone with a higher zone clearing signal, and making electricity exchange zone energy balance of corresponding nodal net energy injections of nodes included within the electricity exchange zone and energy exchanges with all interconnected electricity exchange zones.

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Description

Technical field of the invention

[0001] The present invention relates to a method for clearing a multi-zonal electricity market under a flow-based congestion management approach, namely (a) constrained by normal and/or contingency flow constraints on physical lines -nodal configuration at the physical layer- and (b) clearing commercial bilateral exchanges between interconnected bidding zones -zonal configuration at the commercial layer-.The invention also relates to a system adapted for processing bids by electricity market participants of an auction for electricity market commodities, which notably includes a database including model parameters and bid data, a processor coupled to said database and means for publishing auction results to notify the electricity market participants.

Background of the invention

[0002] The European Power Exchanges PXs incorporate congestion management in the day-ahead markets through the activation of two standard models: the exchange-based model or "ATC-based model", or the flow-based model [2]-[3]. The origins and computational framework for the optimal, i.e. maximum, usage of the interconnections in these models is different, although stemming from the same concept: security of supply considering N-1 criterion constraints. These models create a prominent distinction between commercial exchanges and physical branch flows. According to relevant studies performed in the Central-Western European CWE region, the flow-based model results in significantly higher usage of interconnection transmission capacity as compared to the ATC-based model [2], offering enhanced trading opportunities with at least the same level of security of supply. Following such analyses, the flow-based model has been launched in CWE on 21 May 2015.

[0003] Nevertheless, the application of flow-based market coupling induces a significant "flaw" in the clearing of the commercial exchanges, namely the well-known "non-intuitive exchanges" identified in several CWE studies [2]-[8]. Non-intuitiveness occurs solely in the power market -not in other commodity markets- due to the second Kirchhoff law, defining the use of Power Transfer Distribution Factors PTDFs for simulating the impact of exchanges on the physical branch flows. Essentially, the flow-based model makes the physical properties of the system visible at the market level. Since several exchanges affect simultaneously -though with different factors and possibly in different directions-, the same branch flow, depending on which flow prevails, it is possible that an exchange from a high-price zone to a low-price zone is cleared, in order to free capacity in a critical branch for the clearing of a more beneficial exchange from low-price zones to high-price zones [3]. Even though non-intuitive exchanges relieve efficiently critical branch saturations leading to the maximum social welfare, wherein the PX essentially acts as a broker matching "direct trade" and "counter-trade" exchanges to optimally use the available transmission resources, such results may be deemed undesirable for market designers and participants [9] since they are perceived -maybe falsely or inadvertently- as unfair anti-competitive behaviour and "price-dumping". Therefore, fairness issues are raised by market participants, who perceive the electricity market as any other commodity market, overlooking the physical properties of the system that induce non-intuitive exchanges.

[0004] To surpass such "flaw", a heuristic iterative algorithm has been developed in CWE, in each iteration of which the counter-exchanges associated with negative PTDFs are ignored, in the meaning of being eliminated, in the computation of the (prevailing) flow on the critical, congested branches [3]. This heuristic process provides no guarantees on the quality of the result, since it does not necessarily converge to the optimum, and it does not give an estimate of the error made [3].

[0005] In the following, the basic conditions related to the standard flow-based and exchange-based models are presented, along with the combined model. The analysis presented herein concerns a single trading period -hour in European day-ahead markets-for illustration purposes. Nevertheless, the generalization of the models to a multi-period framework is straightforward.

[0006] Basic congestion management models are set out hereafter. In the Standard Flow-Based (SFB) Model, the electricity grid is represented as a network of physical nodes or buses connected by transmission lines or branches, as shown in Fig. 1. Due to the physical laws of electricity, branch energy flows are dependent on the net energy injection of all nodes, and are constrained by physical flow limits. Energy injections and flows are balanced at nodal and entire grid level.

[0007] In the classical LP formulation, said Standard Flow-Based SFB nodal model is formulated as described below, with reference to the basic nomenclature below, noting in each case the respective dual variables:

$$\min \textstyle\sum_n (Ps_n \cdot Xs_n - Pd_n \cdot Xd_n) \qquad (1)$$

subject to:

a supply volume capacity constraint:

$$Xs_n \leq Qs_n : Rs_n \geq 0, \forall n \tag{2}$$

a demand volume capacity constraint:

$$Xd_n \leq Qd_n : Rd_n \geq 0, \forall n \tag{3}$$

line power flow capacity limits:

$$FL_l \leq FL_l^{up} : Rfl_l^{up} \geq 0, \forall l (4)$$

$$FL_l \geq FL_l^{lo} : Rfl_l^{lo} \geq 0, \forall l (5)$$

a nodal net injection and system energy balance:

$$\sum_n (NI_n) = 0 : L_n, \forall n \tag{6}$$

wherein transmission line power flow FL_l, is defined as

$$FL_l \equiv FL_l (NI_n) = \sum_n PTDF_{l,n} \cdot NI_n \tag{7}$$

and net injection in node n, NI_n, is defined as

$$NI_n = Xs_n - Xd_n \tag{8}$$

[0008] The solution of the SFB mode! attains:

1. a clearing price for each node, L_n,
2. cleared supply energy volumes Xs_n of respective supply offers, whose offer price is lower or equal to the corresponding nodal clearing price,
3. cleared demand energy volumes Xd_n of respective demand bids, whose offer price is greater or equal to the corresponding nodal clearing price,
4. transmission line flows FL_l that are lower than or equal to the respective flow limits,
5. and energy balance at each node and at entire grid level.

[0009] A further basic congestion management model consists of a Standard Exchange-Based SEB model wherein Multi-zonal electricity markets are represented as a set of interconnected bidding zones; trading activities result in exchanges between interconnected bidding zones as illustrated in Fig. 2. Energy supply offers and demand bids are submitted to the Market Operator that is responsible for each bidding zone. An overall optimization model is executed for all bidding zones, determining the accepted and rejected quantities of supply offers and demand bids, along with the clearing prices per bidding zone. Inter-zonal energy exchanges between interconnected bidding zones should be cleared with a direction from the less expensive bidding zone to the more expensive bidding zone, thus on an intuitive manner, based on the respective bidding zones' price differences. The overall optimization problem takes into account that energy volumes of supply, demand and inter-zonal exchanges should be balanced at zone and entire market level.

[0010] In the classical LP formulation, said Standard Exchange-Based SEB generalized model is formulated by (1)-(3) and the following equations:

for inter-zonal exchange upper and lower limits:

$$EX_e \leq ATC_e^{up} : Rex_e^{up} \geq 0, \forall e \tag{9}$$

$$EX_e \geq ATC_e^{lo} : Rex_e^{lo} \geq 0, \forall e \tag{10}$$

zonal power balance:

$$ZI_z - \sum_e \left(ZIM_{e,z} \cdot EX_e \right) = 0 : MP_z, \forall z \tag{11}$$

where zonal injection ZI_z is defined as

$$ZI_z = \sum_{n(z)} (Xs_n - Xd_n) = \sum_{n(z)} (NI_n) \tag{12}$$

[0011] It should be noted that the exchange-based model can be applied for an arbitrary set of bidding zones, which aggregate subsets of nodes of the entire grid.

[0012] The solution of this SEB model attains:

1) a market clearing price for each bidding zone, MP_z,
2) cleared supply energy volumes Xs_n of respective supply offers, whose offer price is lower or equal to the corresponding zonal market clearing price,
3) cleared demand energy volumes Xd_n of respective demand bids, whose offer price is greater or equal to the corresponding zonal market clearing price,
4) energy exchange volumes between interconnected bidding zones, EX_e, with a direction from a bidding zone with a lower price to a bidding zone with a higher price, and
5) energy balance at bidding zone and at entire market level.

[0013] The SEB model presented herein is called "Coordinated Net Transmission Capacity CNTC approach" in the EU Commission Regulation 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management [11]. The usage of the SEB model requires an ex-ante computation of branches ATCs, which define the maximum allowable exchange per interconnection. A specific methodology has been developed by European Transmission System Operators TSOs employing the N-1 criterion for the exogenous computation of the Net Transfer Capacity NTC, and subsequently for the calculation of ATCs. It should be noted here that the classical form of the exchange-based or ATC-based, model concerns the maximum allowable exchange on interconnections only, not on intra-zonal branches. However, the flow limits of intra-zonal branches play a critical role in the computation of the interconnection NTCs [10], thus the derived interconnection ATCs implicitly internalize flow limits of all system branches.

[0014] On the other hand, in a SFB model, the physical constraints of the grid elements are directly embedded in the problem formulation. In this concept, for a given security of supply domain, theoretically the ATC solution space is a subset of this security domain, while the flow-based solution space constitutes the full security domain itself [2]-[3].

[0015] Both aforementioned models SFB and SEB, upon power-flow or exchange volume binding constraints, result in price differentiation between nodes or bidding zones, respectively.

[0016] A significant inefficiency of SFB, from a market point of view, is that power does not necessarily flow from lower to higher nodal price. However, the SEB model always results in exchanges transacted from a bidding zone with a lower price to a bidding zone with a higher price.

Prior Art

[0017] Current approaches in solving an integrated nodal-flow and zonal-exchange based market model are set out hereafter to start with the so-called Combined Exchange Flow-Based model.

[0018] Vlachos and Biskas [12] presented an integrated intuitive exchange flow-based model, but with a nodal configuration in both the physical layer-congestion management in the network branches- and in the commercial layer -commercial exchanges-. However, this approach considered commercial exchanges in single physical lines, which is not the standard practice in European markets where commercial exchanges are regarded at inter-zonal level (between interconnected bidding zones). The generalization of this nodal/nodal approach to a nodal/zonal approach, as implemented in European markets, is not straightforward however, since it requires a different problem formulation logic and extensive changes in the constituent complementarity conditions as it will be further developed hereafter.

[0019] There is no published scientific literature on the nodal/zonal approach, except from technical reports of the Central Western European CWE region, which document the progress of internal research towards the implementation of the intuitive flow-based modeling in the Day-Ahead Market of CWE, with a hybrid network configuration, as shown in Fig. 3 : a nodal-based configuration for congestion management in network branches, and inter-zonal configuration for commercial exchanges. In order to attain intuitive flow-based solutions in such a framework, CWE applied the so-called "intuitive patch", namely an iterative workaround technique that is further explained in this section below.

[0020] The CWE approach is based on the usage of generation shift keys designated as $GSK_{z,n}$ that denote the distribution factor of zonal injection in its internal nodes, nodal injections, namely:

$$NI_n = GSK_{z,n} \cdot ZI_z \quad (13)$$

According to the EU Commission Regulation 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management [11], Generation Shift Key means "a method of translating a net position change of a given bidding zone into estimated specific injection increases or decreases in the common grid model", and "the best forecast of the relation of a change in the net position of a bidding zone to a specific change of generation or load in the common grid model".

[0021] Following the standard definitions of the flow-based model (1)-(6), combined with (11) as power balance and equation (13), a Combined Exchange Flow-Based CEFB model is formulated. The definition of power flow on lines (7) is transformed to:

$$FL_l \equiv FL_l\ (ZI_z) = \sum_n PTDF_{l,n} \cdot GSK_{z,n} \cdot ZI_z = \sum_z ZPTDF_{l,a} \cdot ZI_z \quad (14)$$

[0022] The term $PTDF_{l,n} \cdot GSK_{z,n}$ practically represents the power transfer distribution factor of zonal net injection ZI_z on line flow FL_l, denoted hereafter as $ZPTDF_{l,z}$. The model practically is a "zonal-flow" model, which resembles a standard nodal model, where nodes correspond here to bidding zones.

[0023] In the CWE approach, the GSK factor are exogenous static parameters, i.e. they represent a user-defined, static distribution of zonal to nodal injection. To this extent, the approach resolves theoretically to a suboptimal solution, since the solution space is defined by the values of the static, user-defined GSK factors.

[0024] However, the plain CEFB model may result to non-intuitive directional exchanges, i.e. exchanges from a higher price zone to a lower price zone. In the following, a firm theoretical ground to anchor the presence (by definition) of non-intuitive exchanges is provided. Such presence is explained by further analyzing KKT conditions of the formulated problem. Substituting in (14) the ZI_z by equation (11), and then substituting FL_l from (14) to (4), (5), the power flow constraints are formulated as:

$$\sum_z \left(ZPTDF_{l,z} \cdot \sum_e \left(ZIM_{e,z} \cdot EX_e\right)\right) \leq FL_l^{up} : Rfl_l^{up} \geq 0,\ \forall l \quad (15)$$

$$\sum_z \left(ZPTDF_{l,z} \cdot \sum_e \left(ZIM_{e,z} \cdot EX_e\right)\right) \geq FL_l^{lo} : Rfl_l^{lo} \geq 0,\ \forall l \quad (16)$$

Now, by defining:

$$\delta ZPTDF_{l,e} = \sum_z ZPTDF_{l,z} \cdot ZIM_{e,z} \quad (17)$$

constraints (15), (16) are simplified to

$$\sum_e \left(\delta ZPTDF_{l,e} \cdot EX_e\right) \leq FL_l^{up} : Rfl_l^{up} \geq 0,\ \forall l \quad (18)$$

$$\sum_e \left(\delta ZPTDF_{l,e} \cdot EX_e\right) \geq FL_l^{lo} : Rfl_l^{lo} \geq 0,\ \forall l \quad (19)$$

The KKT condition of variable EX_e is formulated as follows:

$$\sum_z \left(ZIM_{e,z} \cdot MP_z \right) + \sum_l \left(\delta ZPTDF_{l,e} \cdot \left(Rfl_l^{up} - Rfl_l^{lo} \right) \right) = 0 : EX_e, \ \forall e \qquad (20)$$

[0025] The physical volume of each exchange, is driven explicitly by the optimization of the objective (1) and the power flow constraints of (4), (5). Each physical flow is a coupled contribution (through $\delta ZPTDF_{l,e}$) of all branch exchanges. Equivalently, each inter-zonal exchange e affects all physical flows, and reversely, all physical flows binding constraints affect the condition (20) for each exchange e. In the optimal solution, for each physical flow in a branch *l*, FL_l, at most one of (18) or (19) may be binding, that is, at most one of Rfl_l^{up}, or Rfl_l^{lo} may be positive. In addition, each $\delta ZPTDF_{l,e}$ contribution may be positive or negative. The above statements result in the following:

- the second term of (20), comprising a sum of product subterms, may be either positive or negative; theoretically, any possible sign combinations in each product subterm, may occur;
- the first term of (20), expressing the zonal price difference between the sending and receiving zone, may be either negative or positive;
- due to the strict equality condition (20), the complement variable (inter-zonal exchange volume) of (20), may be of any direction, independently of the relative zonal price difference sign, as described in the latter § above.

[0026] Since exchanges constitute dependent variables of the problem, their solution is driven by the optimality conditions, derived by physical limits -of supply, demand and physical flows- along with the optimal target. Thus, an arbitrary mix of positive/negative $\delta ZPTDF_{l,e}$ values would result in arbitrary exchange volumes that fit to the optimality conditions of supply, demand and physical flows. In conclusion, the conditions of the CEFB model do not guarantee intuitive solution for the dependent variables EX_e. It should be noted that, depending on the magnitude of each $\delta ZPTDF_{l,e}$ value, the exchange volume between two interconnected bidding zones may be greater than the physical limits of respective physical branches interconnecting these bidding zones, yet the exchange volume is implicitly constrained by physical branch limits.

"Intuitive patch" applied in CWE is presented hereafter.

[0027] To surpass the "flaw" of non-intuitive exchanges, a heuristic iterative algorithm has been developed in CWE, called "intuitive patch", in each iteration of which the counter-exchanges associated with negative $\delta ZPTDF_{l,e}$ are ignored or eliminated in the computation of the (prevailing) flow on the critical/congested branches [3]. Each iteration of this algorithm comprises the following steps:

a) a combined exchange flow-based optimization problem is solved and all respective clearing prices, MP_z, are computed.

b) Then, an "intuitiveness check" routine is performed on the attained solution. In this check, the welfare W_e of each exchange EX_e is computed as follows:

$$W_e = \sum_z \left(ZIM_{e,z} \cdot MP_z \cdot EX_e^* \right) \qquad (21)$$

where EX_e^* is the optimal value of the EX_e variable (solution of the problem in step (a)) in the current iteration of the algorithm. If all exchange welfares are positive, denoting that all bilateral exchanges are intuitive, then the iterative algorithm terminates.

c) Otherwise, in case there exists at least one exchange with $W_e < 0$ (non-intuitive exchange), then the following constraints are formed for all physical flow congested line branches, indexed here as "critical branch" subset, $cl \subseteq l$:

- if the branch physical flow constraint is binding at the upper limit, then (18) is replaced by:

$$FL_{cl}^{up} - \sum_e \left(\max\{ \delta ZPTDF_{cl,e} \cdot EX_e, 0 \} \right) \geq 0 \qquad (22)$$

- if the branch physical flow constraint is binding at the lower limit, then (19) is replaced by:

$$-FL_{cl}^{lo} + \sum_e \left(\min\left\{\delta ZPTDF_{cl,e} \cdot EX_e, 0\right\}\right) \geq 0. \quad (23)$$

These modifications applied on branch flow constraints practically eliminate all terms that relieve the active branches' congestion, imposing in such way fictitious tighter physical flow limits on the critical branches.
After the application of patches, through the enforcement of constraints (22) and (23), the algorithm continues with step (a) and the next iteration is processed. It should be noted that patches -constraints (22) and (23)- are applied cumulatively, i.e. patches form previous iterations are not ignored or withdrawn in the following iteration.
The flowchart of the CWE "intuitive patch" iterative algorithm is illustrated in Fig. 4.

[0028] This heuristic approach results in "non-saturated" branches, namely in branches used below their physical capacity, thus leading to a sub-optimal solution in an internal point of the "security of supply domain", not lying upon a borderline of the flow-based constraints polyhedron [3]. This technique provides no guarantees on the quality of the result however, since it does not necessarily converge to the optimum, and it does not give an estimate of the error made [3].

[0029] Direct effects of applying static, pre-defined GSKs are as follows: in a flow-based market setup, before the market clearing, the following processes are performed by the TSOs, as illustrated in Fig. 5:

1) A "base case" is created containing expected grid topology for the next day together with expected net positions of all bidding zones and corresponding flows on all critical branches, called "Critical Network Elements" CNEs. This constitutes a first rough assumption, since accurate production forecasts per node are difficult to retrieve, particularly in a system with large amounts of intermittent power, like wind and photovoltaic. The existence of intermittent generation itself signifies the possible errors in production forecasting, with respect to the actual production in real-time. Large shifts in uncontrollable generation like wind and run-of-river hydro can occur quickly with changes in weather conditions, and have a significant influence on the geographical distribution of power generation.
2) TSOs then define the static GSKs, identify CNEs, the corresponding outages to be taken into account and the Remedial Actions that shall be taken into account ex-ante in the capacity (RAM) calculation. Remedial Action means a measure activated by one or several TSOs, manually or automatically, that relieves or contributes to relieving physical congestions, e.g. redispatching and/or countertrading [13]. Remedial Actions can be applied pre-fault or post-fault and they usually involve redispatching/countertrading costs.
3) TSOs define and apply their operational experience in order to adjust the flow-based domain, by decreasing the Remaining Available Margins of the CNEs, through the "Final Adjustment Value" FAV.
4) TSOs also define the Flow Reliability Margin FRM per CNE, which is calculated based on a statistical evaluation of the deviations between the flows estimated by the flow-based method and the actual flows observed.
5) Nodal PTDFs, GSKs and CNEs are used to calculate the zonal PTDFs, i.e. $ZPTDF_{l,z}$ in equation (14), along with the respective Remaining Available Margins (capacities) of all CNEs. The RAM is computed as follows:

$$\text{RAM} = \text{Fmax} - \text{FRM} - \text{FAV} - \text{Fref},$$

where Fmax denotes the maximum allowed flow on the critical branch, and Fref denotes a reference flow at zero net positions that is obtained by using the calculated zonal PTDF matrix from the base case, with certain forecasted production and consumption per node, as referred in step 1 [13].
6) TSOs subsequently send the parameters calculated in step 4 to the Market Operators to perform the market clearing using the portfolio-based offers/bids submitted by the market participants. The market clearing results comprise the cleared supply/demand quantities, the cleared exchanges between the interconnected bidding zones, and the market clearing prices per zone.

[0030] Then, in markets with portfolio-based bidding, the market participants define their production and consumption schedules -self-scheduling process- according to the traded (bought, sold) energy in each bidding zone, and refine such schedules in real-time -self-dispatch process- according to actual production/consumption conditions. In this self-dispatch process, the actual GSKs are derived, which are in general different from the forecasted GSKs defined at day-ahead level.

[0031] The mismatch between the static pre-defined GSKs and the actual GSKs -based on actual production/consumption at each node- leads to erroneous calculated flows in network branches at day-ahead level -with respect to actual flows-, and thus leads to situations where:

a) some line flow constraints are not binding (active) in the market clearing results, but they may be violated in actual operation considering the cleared supply/demand quantities,

b) whereas some line flow constraints are binding in the market clearing results, but they may not be binding in actual operation considering the cleared supply/demand quantities.

Case (a) above necessitates the use of ex-post Remedial Actions in real-time -mainly redispatching and countertrading- to resolve the line flow violations. Such Remedial Actions lead to an overall increased cost -day-ahead plus remedial actions costs-, or equivalently lower welfare, to the society.

[0032] There is no theoretically "right or wrong" methodology on how to generate GSKs. However, the choice of GSKs influences significantly the market [13]. GSKs are actually the major source of inaccuracies of the applied flow-based parameter (zonal PTDFs) calculation and subsequently of the market clearing results.

[0033] The fundamental element in managing uncertainty in capacity calculation is the reliability margin: Flow Reliability Margin, FRM. The flow may be larger or smaller than anticipated, but if the flow turns out larger, there may be an overload on a CNE. In order to reduce the probability of physical overloads to an acceptable risk level, some of the capacity on a CNE is retained from the market as an FRM, namely the FRM reduces the RAM of a CNE. The FRM per CNE is based on historical registration of the difference between the power flow of a CNE forecasted two days ahead of time and the actual flow.

[0034] The Final Adjustment Value FAV is used to incorporate operational skills and experience that cannot formally be calculated in the flow-based system, by increasing or (usually) decreasing the RAM on a CNE. The FAV is essentially introduced to allow a manual adjustment of the RAM.

[0035] Based on the above, the applied flow-based approach is sub-optimal for three main reasons:

- the applied "intuitive patch" results in "non-saturated" branches, namely in branches used below their physical capacity, thus leading to a sub-optimal solution in an internal point of the "security of supply domain", not lying upon a borderline of the flow-based constraints polyhedron;
- the applied approach uses the static GSKs which lead to erroneous calculated flows in network branches, necessitating the use of ex-post Remedial Actions -mainly redispatching and countertrading- to resolve the line flow violations, and leading to an increased cost to the society;
- the endogenous errors in the calculation of the GSKs urge the TSOs to take preventive measures to restrain the RAM at day-ahead level -and thus the line flows in actual operation-, through the use of the Flow Reliability Margin FRM and the Final Adjustment value FAV. This is a source of further downgrade of the social surplus, since the capacity of the network branches is not fully exploited.

[0036] Additionally, the incorrect GSKs lead to inaccurate zonal clearing prices -derived from the market clearing-, which lead to (a) wrong economic signals to the market participants, and (b) inaccurate congestion income, not corresponding to the actual congestion of the electricity grid.

Aim of the invention

[0037] The present invention aims at providing a solution that proposes a remedy to the aforementioned drawbacks and problems. In this respect, the method according to this invention involves a straightforward approach for solving inter-zonal exchange volumes and nodal injections that retain physical flow limits, notably mixing flows and exchanges in a single multi-clearing model, targets in solving for optimal supply, demand and market exchanges, endogenously bounded by physical constraints, e.g. power flows between nodes and transmission physical limits. In this sense, given:

- the energy supply and demand price offers/bids at each node,
- the physical flow limit of each transmission line -between connected/neighboring nodes-, and
- the technical constraints of energy volumes, if any, e.g. maximum and minimum volume, ramp-rates, etc., as continuous convex functions of respective energy volumes,

an integrated mixed nodal-zonal flow-exchange based market model solution method should thus be provided. In the way to solve the problem, there is a need to the generalization of this nodal/nodal approach to a nodal/zonal approach, as implemented in European markets, which is not straightforward however, since it requires a different problem formulation logic and extensive changes in the constituent complementarity conditions as analytically explained in this invention.

[0038] The present invention thus needs to provide a method for the creation of an integrated exchange-based and flow-based model, which attains simultaneously (a) intuitive exchanges between interconnected bidding zones, and (b) maximum flows at the critical intra-zonal and inter-zonal branches, up to their physical limits. The resulting model practically represents two issues with the problem that they are forced to equilibrate:

a) the first aim is to maximize supply/demand surplus subject to respective supply/demand limits;

b) the second to maximize intuitive branch exchanges subject to respective boundaries of exchange volumes as imposed by physical flow limits.

[0039] The model exhibits a hybrid network configuration: (a) a nodal-based network for the congestion management, defining a physical layer and (b) a zonal configuration for the commercial exchanges between the market participants, defining a so-called commercial layer. This hybrid configuration conforms perfectly to the currently applied scheme in Europe, where the "flow-based" approach -along with a hybrid nodal/zonal configuration- is the preferred congestion management modeling approach according to the Capacity Allocation and Congestion Management Network Code CACM NC [1] for the day-ahead and intra-day electricity markets.

Summary of the invention

[0040] With regard to the preceding, it is proposed according to the invention a method for processing bids that are submitted by market participants in an auction for electricity market commodities, comprising the following steps:

retrieving model parameters and bid data for the electricity market commodities;
applying the model parameters and bid data to equations representative of an electricity market, the equations including at least one variable to be determined;
simultaneously solving the equations for at least one variable, said solving being performed iteratively or in one shot to determine at least one variable; and
publishing results of the auction to notify the market participants;
particularly wherein said publishing includes solutions of the at least one variable of quantities and/or clearing prices for the electricity market commodities.

[0041] The effect of the invention in the technical process of congestion management in an electricity network and the computation of the constituent power flows is the following: the methods in the known literature concerning the computation of the power flows and congestion management in electricity networks, under zonal commercial exchanges conditions, lead to erroneous calculated flows in network branches at day-ahead level -with respect to actual flows in real-time-, and thus result in the computation of nodal supply and demand electricity quantities that:
in some cases, cause the violation of the physical limits of some network lines, leading to problematic operation of the electricity network and non-realizable scheduling of the power units, whereas in some other cases, do not utilize the full capacity of the network lines for transferring electricity among the network nodes.
[0042] According to a further embodiment of the method according to the invention used for conducting an auction for an electricity market, the method comprises the steps of:

opening a data collection process of the auction of the electricity market to receive bids on electricity market commodities from market participants;
receiving the bids on the electricity market commodities;
closing the data collection process of the auction of the electricity market; and simultaneously processing the bids to determine results for the electricity market.

Particularly, it further comprises validating the bids for the electricity market, and still further comprises publishing the results of the auction respectively, more particularly wherein publishing includes at least one of the following:

- posting the results of the computation on an electronic media; and/or
- communicating the results to the market participants via an electronic communication.

Still more particularly, said posted results include public information accessible by market participants; yet more particularly wherein the electronically communicated results include private information, or/and wherein the electronic communication includes at least one of the following means: e-mail, text messaging, and facsimile.
[0043] According to a particular embodiment of the method according to the invention used for participating in an electricity market auction conducted by a market operator for market participants, the method comprises the steps of:

establishing a communication link by a market participant with a market operator;
communicating a bid for electricity market commodities from the market participant to the market operator; and
receiving results of the auction from the market operator by the market participant, the results being simultaneously generated.

Said results of the auction can be received notably via an electronic communication, particularly wherein said receiving includes: accessing a network location; and entering a password at the network location to receive the results, or/and wherein the results of the auction are published on a publicly accessible location.

[0044] According to a technically remarkable embodiment of the method of the invention, which is notably used including for the realization of the system as set out hereinafter, said solving computes, and/or said auction results include, at least one of the following market elements: scheduled quantities, and/or exchange quantities, and/or clearing prices for the electricity market commodities, and power flow transmission usage;

said publishing includes posting solution of at least one variable of scheduled quantities, and/or exchange quantities, and/or clearing prices for the electricity market commodities. Said method, respectively system computer or medium, further comprises matching the bid data, of scheduled quantities, and/or exchange quantities, and/or clearing prices to power grid locations, wherein power grid location represents at least one of the following: a power system bus, a power system node, a power system zone, a group or arbitrary number of buses or nodes or zones.

A market participant further submits a bid including a set of points defining a price and quantity curve for electricity market commodities;

wherein the bids for the electricity market include at least one-time interval for electric market commodities;

wherein said process or solving includes performing an optimization or computation process;

wherein the optimization or computation process includes solving (iteratively or in one-shot) a set of necessary variables and conditions included in a set of simultaneous equations;

wherein process or solving, is executed for multiple time intervals, either altogether or separately; and

wherein process or solving, is performed after an acceptance time for new bids and bid modifications.

[0045] There is thus proposed according to the present invention a technical process wherein the effect of the invention is set out hereafter: said process concerns the computation of the supply and demand in each node of an electricity network and the computation of the power flows in the network lines, in order to manage the congestion in the network in a secure way i.e. technically, to ensure thereby that the transmission line flows are lower than or equal to the respective flow limits- under commercial rules that must be satisfied in parallel for the computation of the commercial exchanges between the interconnected network zones.

[0046] The volumes of supply and demand are physical energy quantities, which define the way the electricity physically flows in the network. Nevertheless, the evaluation, resp. computation of the physical electricity supply and demand quantities, will necessarily follow the physical flow rules, but in addition thereto, they must also follow rules concerning the commercial exchanges between the interconnected network zones. So there are two constraints: a physical one, i.e. the technical aspect, and a commercial one.

[0047] The invention achieves the computation of appropriate nodal supply and demand electricity quantities, and in parallel appropriate power flows in the electricity network lines, such that the technical limits of the network are not violated in real-time operation, and the maximum possible transfer of electricity is attained among the network nodes. The sole economic effect of the invention is that, in parallel with the essentially technical process, the total social welfare of the nodal supply and demand electricity quantities and the commercial exchanges between the electricity network zones is optimized.

[0048] According to a technically advanced embodiment of the method according to the invention used for the computation of the power flow in an electricity network and congestion management of the power flows in the electricity network under exchanges rules, the electricity network comprises at least one of the following items:

a plurality of nodes of a physical electricity network;

a plurality of transmission lines interconnecting said network nodes, wherein a line energy physical flow is constrained by an upper limit, where said energy physical flow is defined as a linear function of nodal energy injections, where said nodal energy injection is defined as energy injected minus energy absorbed in the respective node;

a plurality of electricity exchange zones that group an arbitrary number of nodes;

a plurality of energy exchanges transacted between interconnected zones;

a plurality of supply orders for an energy injection at least in one node; and

a plurality of demand orders for energy absorption at least in one node, remarkable in that said method implements at least one of the following actions:

setting an electricity exchange system clearing signal for the said electricity exchange zones;

setting the schedule of supply energy volumes to be injected in each node, with supply order thresholds that are lower than or equal to the corresponding electricity exchange zone clearing signal;

setting the schedule of demand energy volumes to be absorbed in each node, with demand order thresholds that are higher than or equal to the corresponding electricity exchange zone clearing signal;

setting the transmission line flows lower than or equal to the respective flow limit;

setting the energy exchange volumes to be transferred between electricity exchange zones, with direction from

an electricity exchange zone with a lower clearing signal to an electricity exchange zone with a higher clearing signal;
making an electricity exchange zone energy balance of corresponding nodal net energy injections of nodes included within the electricity exchange zone, and energy exchanges with all interconnected electricity exchange zones.

[0049] According to a more advanced embodiment of the method according to the invention, it comprises in the clearing condition of nodal supply orders only positive terms with respect to the contribution of nodal supply injection to transmission line flows, i.e. positive PTDFs with respect to the transmission line flow upper limit, on the one hand, and negative PTDFs with respect to the transmission line flow lower limit, on the other hand. The clearing condition of supply orders in node n comprises at least a formulation as follows:

$$Ps_n - MP_z + Rs_n + \textstyle\sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0} \cdot Rfl_l^{up} - \textstyle\sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0} \cdot Rfl_l^{lo} + \textstyle\sum_j a_{j,sn}\big|_{a_{j,sn}\geq 0} \cdot R_j - \textstyle\sum_l a_{j,sn}\big|_{a_{j,sn}\leq 0} \cdot R_j \geq 0 \perp Xs_n \geq 0, \forall n \quad (62)$$

In this condition, the variable Rs_n may particularly be defined by the condition

$$Xs_n \leq Qs_n \perp Rs_n \geq 0,\ \forall n. \quad (51)$$

It may comprise in the clearing condition of nodal demand orders only positive terms with respect to the contribution of nodal demand absorption to transmission line flows, consisting of positive PTDFs with respect to the transmission line flow lower limit, on the one hand, and negative PTDFs with respect to the transmission line flow upper limit, on the other hand, wherein the clearing condition of demand orders in node *(n)* comprises at least a formulation as follows:

$$-Pd_n + MP_z + Rd_n - \textstyle\sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0} \cdot Rfl_l^{up} + \textstyle\sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0} \cdot Rfl_l^{lo} + \textstyle\sum_j a_{j,dn}\big|_{a_{j,dn}\geq 0} \cdot R_j - \textstyle\sum_l a_{j,dn}\big|_{a_{j,dn}\leq 0} \cdot R_j \geq 0 \perp Xd_n \geq 0, \forall n \quad (63)$$

Particularly in this condition, the variable Rd_n is defined by the condition

$$Xd_n \leq Qd_n \perp Rd_n \geq 0,\ \forall n \quad (52)$$

[0050] According to a yet more advanced embodiment of the method according to the invention, in said conditions, Rfl_l^{up} is defined by condition

$$\textstyle\sum_n PTDF_{l,n} \cdot (Xs_n - Xd_n) \leq FL_l^{up} \perp Rfl_l^{up} \geq 0\ \forall l \quad (53)$$

and Rfl_l^{lo} is defined by condition:

$$\textstyle\sum_n PTDF_{l,n} \cdot (Xs_n - Xd_n) \geq FL_l^{lo} \perp Rfl_l^{lo} \geq 0,\ \forall l \quad (54)$$

and R_j is defined by condition:

$$b_j - \textstyle\sum_{sn} a_{j,sn} \cdot Xs_n - \textstyle\sum_{dn} a_{j,dn} \cdot Xd_n - \textstyle\sum_{sn} a_{j,u} \cdot X_u \geq 0 \perp R_j \geq 0 \quad (40.b)$$

The clearing condition of an inter-zonal exchange (e) may further comprise at least a formulation as follows:

$$-MP_{z'} + MP_z + PPd^{+}_{e(z,z')} \geq 0 \perp PPd^{+}_{e(z,z')} \geq 0\,,\ \forall e \tag{58}$$

$$+MP_{z'} - MP_z + PPd^{-}_{e(z,z')} \geq 0 \perp PPd^{-}_{e(z,z')} \geq 0\,,\ \forall e \tag{59}$$

$$-MP_{z'} + MP_z + PPd^{+}_{e(z,z')} \geq 0 \perp EX^{+}_{e(z,z')} \geq 0\,,\ \forall e \tag{60}$$

$$+MP_{z'} - MP_z + PPd^{-}_{e(z,z')} \geq 0 \perp EX^{-}_{e(z,z')} \geq 0\,,\ \forall e. \tag{61}$$

Said variable MP_z may be defined as the electricity exchange zone clearing signal, and wherein the energy balance constraint of zone (z) is defined as:

$$\sum_{n(z)}(Xs_n - Xd_n) - \sum_e\left(ZIM_{e,z} \cdot EX_e\right) = 0 \ \perp MP_z, \forall\, z\,. \tag{55}$$

[0051] According to a specific embodiment of the method according to the invention, it is proposed an evaluation method wherein said electricity exchange system is allocated to a market, wherein said electricity exchange zones consist of bidding zones, further wherein said clearing signal is assigned to a clearing price, and further wherein said orders represent offers and bids.

[0052] To summarize, it is thus remarkably proposed according to the present invention a method yielding a solution based on the following items:

- a market clearing price for each bidding zone,
- cleared supply energy volumes of respective supply offers, whose offer price is lower or equal to the corresponding zonal market clearing price,
- cleared demand energy volumes of respective demand bids, whose offer price is greater or equal to the corresponding zonal market clearing price,
- transmission line flows that are lower than or equal to the respective flow limit,
- energy exchange volumes between bidding zones, with direction from a bidding zone with a lower price to a bidding zone with a higher price,
- an energy balance at nodal level, implicitly attained through the use of PTDFs, and
- an energy balance at bidding zone level, consistent with cleared exchange levels between interconnected bidding zones.

[0053] The invention also relates to a system adapted for processing bids by electricity market participants of an auction for electricity market commodities, which notably comprises a database including model parameters and bid data, a processor coupled to said database and means for publishing auction results to notify the electricity market participants. Said system is used for processing bids by electricity market participants of an auction for electricity market commodities. Said system comprises:

a database including model parameters and bid data, the model parameters and bid data being applied to equations representative of the electricity market, the equations including at least one variable to be determined;

a processor coupled to said database, the processor for simultaneously solving the equations for at least one variable to be determined, the solving being performed iteratively to determine at least one variable according to a predetermined objective or criteria; and means for publishing auction results to notify the electricity market participants, where a publishing mean executes at least one of the following actions: it posts solutions of at least one variable on an electronic media for the participants to retrieve, and/or it electronically communicates the solution for at least one variable to the electricity market participants.

Said publishing may include at least posting and electronically communicating solution of at least one variable.

[0054] According to a particular embodiment of the system according to the invention used for conducting an auction for an electricity market, it comprises:

a computer server coupled to a communication network, said computer server operating the electricity market;

a plurality of electronic devices coupled to the communication network, said electronic devices in communication with said computer server for submitting bids for electricity market commodities;
and at least one database coupled to said computer server, said at least one database storing the submitted bids, power grid model parameters, and electricity market parameters, said computer server simultaneously processing the submitted bids to determine the auction results;

Said electronic devices particularly include at least one of the following items: computer, facsimile, telephone, and personal communication device, or/and said computer server further publishes the results of the auction available to said electronic devices. The publishing of the results includes at least one of the following: posting on the communication network and/or electronically transmitting.

[0055] According to a more particular embodiment of the system according to the invention, it includes a computer-readable medium, having stored thereon sequences of instructions. Said sequences of instructions include instructions, when executed by a processor, cause the processor to:

retrieve modeling parameters and a plurality of bids for electricity market commodities;
apply the modeling parameters and bids to equations representative of an electricity market, the equations including at least one variable to be determined;
solve the equations for at least one variable, said solving being performed iteratively to determine the at least one variable according to a predetermined objective or criteria;
and publish results of the auction to notify the market participants.

[0056] According to a yet more particular embodiment of the system according to the invention, said computer-readable medium, having stored thereon sequences of instructions, may also cause the processor to

- establish a communication link by a market participant with a market operator;
- communicate a bid for electricity market commodities from the market participant to the market operator; and
- receiving results of the auction from the market operator by the market participant, the results being simultaneously generated.

[0057] According to a still more particular embodiment of the system according to the invention, it includes at least one computer programmed to execute a process for participating in an electricity market in which a computer server operated by a market operator conducts an auction for electricity market commodities. Said process comprises the steps of :

transmitting electronic signals to establish a communication link between a market participant computer and the computer server;
generating at least one bid for the electricity market commodities; and
causing electronic signals representing at least one bid to be sent to the computer server for submission of at least one bid to be submitted to the auction, the bids being simultaneously processed to determine results of the auction.

In particular, the process may further comprise determining results of the auction based on at least one bid and causing electronic signals representing the results of the auction to be sent from the computer server to the market participant computer.

[0058] According to a preferred embodiment of the system according to the invention, it includes at least one computer which is programmed to process bids submitted by market participants for electricity market commodities, wherein said process comprises the following items:

receiving electronic signals representing electricity market model parameters;
receiving electronic signals representing the bids submitted by the market participants;
applying the electricity market model parameters and bids to equations representative of an electricity market, and including at least one variable to be determined;
iteratively computing solutions to at least one variable until the at least one variable satisfies a predetermined objective or criteria;
determining results of the auction based on the at least one variable being determined;
and transmitting electronic signals representing the results of the auction to be sent to publish the results of the auction.

In particular, the results of auction are published on an electronic network.

[0059] According to a further embodiment of the system according to the invention, it is used for determining results of an auction conducted for electricity market commodities of an electricity market, wherein the system comprises:

means for storing model parameter and bid data;
means for reading the model parameters and bid data from said means for storing; means for utilizing the model parameters and bid data to determine results of the auction; and means for publishing the results of the auction.

[0060] According to a specific embodiment of the system according to the invention, said electricity market constitutes one integrated electricity market or a set of coupled electricity markets, and comprises at least one of the following items:

a plurality of nodes of a physical electricity network;
a plurality of transmission lines interconnecting said network nodes, wherein a line energy physical flow is constrained by an upper limit, where said energy physical flow is defined as a linear function of nodal energy injections, where said nodal energy injection is defined as energy injected minus energy absorbed in the respective node;
a plurality of electricity exchange zones that group an arbitrary number of nodes;
a plurality of energy exchanges transacted between interconnected zones;
a plurality of supply bids, for an energy injection at least in one node; and
a plurality of demand bids for energy absorption at least in one node,
wherein electricity market commodities include at least one of the following electric energy, reserve capacity, and transmission capacity;
wherein said solving computes, and or the said (auction) results include, at least one of the following: scheduled quantities, and/or exchange quantities, and/or clearing prices for the electricity market commodities, and power flow transmission usage;
wherein said publishing includes posting solution of at least one variable of scheduled quantities, and/or exchange quantities, and/or clearing prices for the electricity market commodities.

Said system further comprises matching the bid data of scheduled quantities, and/or exchange quantities, and/or clearing prices to power grid locations, wherein power grid location represent at least one of the following: a power system bus, a power system node, a power system zone, a group or arbitrary number of buses or nodes or zones;
wherein a market participant submits a bid including a set of points defining a price and quantity curve for electricity market commodities;
wherein the bids for the electricity market include at least one time interval for electric market commodities;
wherein said process or solving includes performing an optimization or computation process;
wherein the optimization or computation process includes solving (iteratively or in one-shot) a set of necessary variables and conditions included in a set of simultaneous equations;
wherein process or solving, is executed for multiple time intervals, either altogether or separately; and
wherein process or solving, is performed after an acceptance time for new bids and bid modifications.

[0061] The most significant features of the solution achieved with this invention, which attains the objectives of a mixed nodal-zonal flow-exchange based market model, are the following: no static, user-defined GSK factors are used, and no specific static distribution of zonal injection to internal nodes is assumed.
The physical system parameters are not modified -no PDFT parameters elimination, i.e. the physical system is originally represented.
The formulation constitutes a single integrated model that can be solved at one stage, resulting in that no heuristic iterative process or algorithm is required.

[0062] As illustrated in Fig. 6, the solution method which is provided with this invention leads to:

- the optimal solution in terms of social welfare, without the need for application of economically inefficient Remedial Actions to overcome the inaccuracies in the GSKs, since there are no GSKs in this method,
- correct zonal market clearing prices, leading to correct economic signals and accurate congestion income, and
- technically no overflows in network branches -stemming from inaccuracies in the GSKs- in actual operation considering the cleared supply/demand quantities.

[0063] Thanks to a further embodiment of the solution method provided by the present invention, the problem of multi-zonal electricity market with intuitive exchanges between interconnected bidding zones and nodal configuration for the flow-based congestion management is solved with the technical means provided.

[0064] The solution method proposed with the invention combines the standard nodal flow model of said physical layer from an essentially technical point of view, with intuitive clearing conditions of inter-zonal exchanges of said commercial layer.

[0065] The physical flow constraints are modeled at nodal level, i.e. equations (2)-(5), and definitions (7), (8). Instead of a system level power balance (6), zonal power balance equations (11)-(12) are used. The concise formulation is provided in the following, to start with the supply and demand volume capacity constraint:

$$Xs_n \leq Qs_n \perp Rs_n \geq 0, \forall n \tag{24}$$

$$Xd_n \leq Qd_n \perp Rd_n \geq 0, \forall n \ ; \tag{25}$$

further the line power flow capacity limits:

$$FL_l \ \leq FL_l^{up} \perp Rfl_l^{up} \geq 0, \forall l \tag{26}$$

$$FL_l \ \geq FL_l^{lo} \ \perp Rfl_l^{lo} \geq 0, \forall l \tag{27}$$

where transmission line power flow FL_l is defined as:

$$FL_l \ \equiv \sum_n PTDF_{l,n} \cdot (Xs_n - Xd_n)$$

and finally the power balance:

$$ZI_z - \sum_e \left(ZIM_{e,z} \cdot EX_e\right) = 0 \ \perp MP_z \,, \forall z \tag{28}$$

where zonal injection AI_z is defined as:

$$ZI_z = \sum_{n(z)}(Xs_n - Xd_n) = \sum_{n(z)}(NI_n).$$

[0066] In this sense, the fundamental parameters affecting the power flows are nodal net injections $NI_n = Xs_n - Xd_n$. No GSK parameters are considered, thus nodal net injections are primal drivers of the problem, and the distribution of zonal injections to internal nodes is resolved by optimality conditions. Moreover, no PTDF modification (elimination) is assumed with respect to power flows, thus the solution space is not reduced -as in the said intuitive patch-, and physical flows may reach their binding limits. No artificial tighter limits are imposed to the "critical branches" through the said elimination of specific PTDFs.

[0067] Despite the introduction of exchange variables in the model (24)-(28), its solution, as a standard LP optimization problem with objective (1), still does not guarantee intuitive exchanges. Moreover, it may yield paradoxically accepted or rejected supply/demand bids with respect to the zonal clearing price MP_z -marginal/shadow price of constraint (28)-. These facts are theoretically expected and explained by further analyzing the KKT conditions of the formulated problem:

a) exchange variables are dependent variables, as in the case explained in section 2.

b) KKT optimality conditions implicitly define nodal prices that prevail over the zonal prices, and drive the optimal solution of Xs_n and Xd_n. These nodal prices are implicitly formed as follows:

$$M_n = MP_z + \sum_l PTDF_{l,n} \cdot \left(Rfl_l^{up} - Rfl_l^{lo}\right) \tag{29}$$

[0068] Thus, supply volumes may be cleared at a zonal price lower than their respective bid, or equivalently, demand volumes may be cleared at a zonal price lower than their respective bid. These cases are collectively called paradoxically accepted orders. In fact, the LP solution of (1), (24)-(28) is identical to the solution of the SFB model.

[0069] In order to attain a solution with intuitive exchanges and non-paradoxically cleared supply/demand volumes, the following conditions must hold:

a) supply and demand volumes must be cleared, only under a positive surplus of their bid with respect to the zonal clearing price, i.e.

$$Xs_n: \begin{cases} > 0, \text{if } MP_z \geq Ps_n \\ = 0, \text{if } MP_z < Ps_n \\ free, \text{if } MP_z = Ps_n \end{cases} \tag{30}$$

and

$$Xd_n: \begin{cases} > 0, \text{if } MP_z \leq Pd_n \\ = 0, \text{if } MP_z > Pd_n \\ free, \text{if } MP_z = Pd_n \end{cases} \tag{31}$$

b) Considering that EX_e can be split in two directional non-negative components $EX_e = EX_e^+ - EX_e^-$, these directional exchange volumes must be cleared only under a positive surplus with respect to the zonal clearing price difference, i.e.

$$EX_{e(z,z')}^+: \begin{cases} > 0, \text{if } MP_{z'} > MP_z \\ = 0, \text{if } MP_{z'} < MP_z \\ free, \text{if } MP_{z'} = MP_z \end{cases} \tag{32}$$

and

$$EX_{e(z,z')}^-: \begin{cases} = 0, \text{if } MP_{z'} > MP_z \\ > 0, \text{if } MP_{z'} < MP_z \\ free, \text{if } MP_{z'} = MP_z \end{cases} \tag{33}$$

[0070] In a preferred embodiment of the solution method proposed according to the invention, the above conditions (30) - (33) are formulated as complementarity equations, associated to the respective variables establishing market clearing conditions; (24)-(28) are formulated also as complementarity equations establishing system conditions.

[0071] These system conditions guarantee that all physical flows will be retained to their limits. The market conditions guarantee that, in a congested flow solution, at most one directional exchange can be intuitively positive per exchange. Market conditions guarantee that supply and demand bids will be cleared intuitively with respect to zonal market clearing price.

[0072] The formulation practically represents two major problems that are forced to equilibrate: the first problem targets at the maximization of supply/demand surplus subject to respective supply/demand limits, whereas the second problem targets at the maximization of intuitive exchanges surplus. In both problems, volumes are subject to boundaries imposed implicitly by physical flow limits. The zonal balance equation equilibrates the two problems by:

- providing the zonal clearing prices, common to both problems, and
- balancing the zonal injections of the 1st problem with the exchange volumes of the 2nd problem.

[0073] In a further preferred embodiment, there is provided the clearing conditions of supply bids, at node level, with respect to the zonal market clearing price, where the node belongs to. Supply clearing should resolve to positive surplus of cleared nodal volumes with respect to the zonal market clearing price.

[0074] A still further preferred embodiment provides the clearing conditions of demand bids, at node level, with respect to the zonal market clearing price, where the node belongs to. Demand clearing should resolve to positive surplus of cleared nodal volumes with respect to the zonal market clearing price.

[0075] A yet further preferred embodiment further provides the clearing conditions for supply and demand, in the case of additional linear constraints that engage nodal supply and demand volumes.

A still more preferred embodiment provides the explicit conditions for defining intuitive exchanges, i.e. exchange volumes transacted from a bidding zone with a lower price to a bidding zone with a higher price.

Further features of the present invention are defined in corresponding subclaims below being understood that the system is notably adapted for carrying out the method as claimed.

[0076] Some exemplary embodiments of the present invention are described more in detail in conjunction with the accompanying drawings. It is to be noted that the embodiments in this invention and features in the embodiments can be mutually combined with each other without conflict.

Brief description of the drawings

[0077]

Fig. 1 represents an illustration of the electricity grid in the known standard flow-based SFB model, where all nodes and single lines are considered, as physical layer.

Fig. 2 represents an illustration of the also known standard exchange-based SEB model, in which the intra-zonal lines and nodes are ignored, and only the commercial layer of exchanges between interconnected bidding zones is considered.

Fig. 3 represents an illustration of the integrated nodal/zonal flow- and exchange-based model, in which both the physical layer - i.e. technical - and the commercial layer are taken into account in the model conditions, showing the overlaying physical and commercial layers in the Combined Exchange Flow Based CEFB model.

Fig. 4 illustrates the solution algorithm of the "intuitive patch" currently applied in CWE region and included in the European day-ahead market solver.

Fig. 5 illustrates the basic design of the current congestion management -flow-based-approach, notably in Europe, where its flaws are revealed leading to increased redispatching cost in real-time and an overall worse solution for the social welfare.

Fig. 6 illustrates the design layout proposed according to this invention, under which the physical parameters of the system PTDFs are not modified, and the calculated flows are correct, leading to overall optimum social welfare for the market participants.

Fig. 7 is an exemplary system block diagram for operating an electricity market according to the principles of the present invention.

Description

[0078] In the latter fig. 7, the Market Participants communicate with the system of the Market Operator with internet connection. Initially, the Market Participants submit energy supply offers and energy demand bids to the Market Operator. These offers and bids are validated and stored at the database of the Market Operator. Then, the Market Operator executes the said method for solving the electricity market problem for all bidding zones, determining the accepted and rejected quantities of supply offers and demand bids, along with the clearing prices per bidding zone. The Market Operator distributes the market results to the Market Participants, who then submit their market schedules to the Transmission System Operator (TSO).

[0079] It is emphasized that the technical mean, in which the method described with this invention is implemented, is the computer server of the Market Operator, based on the offers and bids submitted by the Market Participants and based on the parameters of the electricity network. The system of the Transmission System Operator presented at the right-hand side of Fig. 7 looks fainted, since it is only involved in the currently applied method of the prior art, where redispatching of the schedules submitted by the Market Participants to the TSO is needed, in order to ensure that the transmission line flows are lower than or equal to the respective flow limits. Such activity is not needed when implementing the method described in this invention.

[0080] Preferred embodiments of the invention are described hereafter.

[0081] A first embodiment of this invention provides the clearing conditions of supply bids, at node level, with respect to the zonal market clearing price, where the node belongs to. Supply clearing should resolve to positive surplus of cleared nodal volumes with respect to the zonal market clearing price.

[0082] In said first embodiment, the clearing condition of nodal supply takes into account the shadow (added) value of any constraint that defines an upper bound for the supply volume.

[0083] Supply volumes are constrained explicitly by their respective capacity limits (24), and implicitly by flow constraints (26)-(27). More specifically, each flow constraint defines an upper bound for supply volumes as in the following

$$Xs_n \leq \left(\frac{FL_l^{up} - \sum_{n' \neq n} PTDF_{l,n'} \cdot (Xs_{n'} - Xd_{n'})}{PTDF_{l,n}} + Xd_n \right) \Big|_{PTDF_{l,n} > 0} \perp Rfl_l^{up} \geq 0, \ \forall l \qquad (34)$$

$$Xs_n \leq \left(\frac{FL_l^{lo} - \sum_{n' \neq n} PTDF_{l,n'} \cdot (Xs_{n'} - Xd_{n'})}{-PTDF_{l,n}} + Xd_n\right)\Bigg|_{PTDF_{l,n}<0} \perp Rfl_l^{lo} \geq 0,\ \forall\, l \qquad (35)$$

In the above upper bound implicit definitions, Rfl_l^{up} , Rfl_l^{lo} are interpreted as marginal values of supply decrease, or equivalently of supply upper bound increase, in order to relieve congestion.

[0084] Considering marginal values of supply as in (24), (34) and (35), the clearing condition of supply volumes is expressed as in the following complementarity form:

$$Ps_n - MP_a + Rs_n + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0} \cdot Rfl_l^{up} - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0} \cdot Rfl_l^{lo} \geq 0 \perp Xs_n \geq 0,\ \forall\, n \qquad (36)$$

[0085] A second embodiment of this invention provides the clearing conditions of demand bids, at node level, with respect to the zonal market clearing price, where the node belongs to. Demand clearing should resolve to positive surplus of cleared nodal volumes with respect to the zonal market clearing price.

[0086] In said second embodiment, the clearing condition of nodal demand takes into account the shadow (added) value of any constraint that defines an upper bound for the demand volume.

[0087] Demand volumes are constrained explicitly by their respective capacity limits (25), and implicitly by flow constraints (26)-(27). More specifically, each flow constraint defines an upper bound for demand volumes as in the following:

$$Xd_n \leq \left(\frac{FL_l^{lo} - \sum_{n' \neq n} PTDF_{l,n'} \cdot (Xs_{n'} - Xd_{n'})}{PTDF_{l,n}} + Xs_n\right)\Bigg|_{PTDF_{l,n}>0} \perp Rfl_l^{up} \geq 0,\ \forall\, l \qquad (37)$$

$$Xd_n \leq \left(\frac{FL_l^{up} - \sum_{n' \neq n} PTDF_{l,n'} \cdot (Xs_{n'} - Xd_{n'})}{-PTDF_{l,n}} + Xs_n\right)\Bigg|_{PTDF_{l,n}<0} \perp Rfl_l^{lo} \geq 0,\ \forall\, l \qquad (38)$$

In the above upper bound implicit definitions, Rfl_l^{up} , Rfl_l^{lo} are interpreted as marginal values of demand decrease, or equivalently of demand upper bound increase, in order to relieve congestion.

[0088] Considering marginal values of demand as in (25), (37) and (38), the clearing condition of demand volumes is expressed as in the following complementarity form:

$$-Pd_n + MP_z + Rd_n - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0} \cdot Rfl_l^{up} + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0} \cdot Rfl_l^{lo} \geq 0 \perp Xd_n \geq 0,\ \forall\, n \qquad (39)$$

[0089] A third embodiment of the present invention further provides a generalized extension of said first and second embodiment, i.e. the clearing conditions for supply and demand, in the case of additional linear constraints that engage supply volumes Xs_n, demand volumes Xd_n and other variables Xu namely

$$a_j^T \times x \leq b_j \perp R_j \geq 0 \qquad (40.a)$$

where x^T = [Xs, Xd, Xu], or equivalently

$$b_j - \sum_{sn} a_{j,sn} \cdot Xs_n - \sum_{dn} a_{j,dn} \cdot Xd_n - \sum_{sn} a_{j,u} \cdot X_u \geq 0 \perp R_j \geq 0 \qquad (40.b)$$

[0090] Each constraint j defines an implicit upper bound of Xs_n and Xd_n as in the following:

$$Xs_n \leq \frac{b-\sum_{i\neq sn}(a_{j,i}\cdot x_i)}{a_{j,sn}}\bigg|_{a_{j,sn}>0} \perp R_j \geq 0, \ \forall j \tag{41}$$

$$Xs_n \leq \frac{b-\sum_{i\neq sn}(a_{j,i}\cdot x_i)}{-a_{j,sn}}\bigg|_{a_{j,sn}<0} \perp R_j \geq 0, \ \forall j \tag{42}$$

$$Xd_n \leq \frac{b-\sum_{i\neq dn}(a_{j,i}\cdot x_i)}{a_{j,dn}}\bigg|_{a_{j,dn}>0} \perp R_j \geq 0, \ \forall j \tag{43}$$

$$Xd_n \leq \frac{b-\sum_{i\neq dn}(a_{j,i}\cdot x_i)}{-a_{j,dn}}\bigg|_{a_{j,dn}<0} \perp R_j \geq 0, \ \forall j \tag{44}$$

[0091] In the above upper bound implicit definitions, R_j is interpreted as the marginal value of supply or demand decrease, or equivalently of supply or demand upper bound increase, in order to relieve congestion.

[0092] Considering additional marginal values of supply, as in (41) and (42), the clearing condition of supply volumes is expressed as in the following extended complementarity form:

$$Ps_n - MP_z + Rs_n + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0}\cdot Rfl_l^{up} - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0}\cdot Rfl_l^{lo} + \sum_j a_{j,sn}\big|_{a_{j,sn}\geq 0}\cdot R_j - \sum_l a_{j,sn}\big|_{a_{j,sn}\leq 0}\cdot R_j \geq 0 \perp Xs_n \geq 0, \ \forall n \tag{45}$$

[0093] Considering additional marginal values of demand as in (43) and (44), the clearing condition of demand volumes is expressed as in the following extended complementarity form:

$$-Pd_n + MP_z + Rd_n - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0}\cdot Rfl_l^{up} + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0}\cdot Rfl_l^{lo} + \sum_j a_{j,dn}\big|_{a_{j,dn}\geq 0}\cdot R_j - \sum_l a_{j,dn}\big|_{a_{j,dn}\leq 0}\cdot R_j \geq 0 \perp Xd_n \geq 0, \ \forall n \tag{46}$$

[0094] A forth embodiment of the present invention provides the explicit conditions for defining intuitive exchanges, i.e. exchange volumes transacted from a bidding zone with a lower price to a bidding zone with a higher price.

[0095] An exchange EX_e is considered as the difference of two directional non-negative components $EX_e = EX_e^+ - EX_e^-$, only one of which might be non-zero. Directional exchange volumes should be cleared intuitively with respect to the zonal clearing price difference.

[0096] For each direction of exchanges, the respective positive price difference variable *PPd* is defined as

$$-MP_{z'} + MP_z + PPd_{e(z,z')}^{+} \geq 0 \perp PPd_{e(z,z')}^{+} \geq 0, \forall e \tag{47}$$

$$+MP_{z'} - MP_z + PPd_{e(z,z')}^{-} \geq 0 \perp PPd_{e(z,z')}^{-} \geq 0, \forall e \tag{48}$$

The conditions impose that only one of the $PPd_{e(z,z')}^{+}$, $PPd_{e(z,z')}^{-}$ might be positive, whereas the other would be zero.

[0097] By defining which direction renders a positive price difference, the following conditions impose that only the directional exchange with $PPd \geq 0$ will be cleared, i.e. may render a positive value; respectively the counter directional exchange with *PPd* = 0 would be zero.

$$-MP_{z'} + MP_z + PPd^{+}_{e(z,z')} \geq 0 \perp EX^{+}_{e(z,z')} \geq 0, \forall e \tag{49}$$

$$+MP_{z'} - MP_z + PPd^{-}_{e(z,z')} \geq 0 \perp EX^{-}_{e(z,z')} \geq 0, \forall e \tag{50}$$

[0098] In summary, conditions (47)-(50) guarantee that cleared exchange volume between two bidding zones are intuitively coherent to the price difference of these zones.

[0099] For the case that there exist no additional linear constraints of type (40) that engage nodal supply and demand volumes, the complete solution method, is the solution of the following set of conditions:

$$Xs_n \leq Qs_n \perp Rs_n \geq 0,\ \forall n \tag{51}$$

$$Xd_n \leq Qd_n \perp Rd_n \geq 0,\ \forall n \tag{52}$$

$$\sum_n PTDF_{l,n} \cdot (Xs_n - Xd_n) \leq FL_l^{up} \perp Rfl_l^{up} \geq 0,\ \forall l \tag{53}$$

$$\sum_n PTDF_{l,n} \cdot (Xs_n - Xd_n) \geq FL_l^{lo} \perp Rfl_l^{lo} \geq 0,\ \forall l \tag{54}$$

$$\sum_{n(z)} (Xs_n - Xd_n) - \sum_e \left(ZIM_{e,z} \cdot EX_e \right) = 0 \perp MP_z, \forall z \tag{55}$$

$$Ps_n - MP_z + Rs_n + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n} \geq 0} \cdot Rfl_l^{up} - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n} \leq 0} \cdot Rfl_l^{lo} \geq 0 \perp Xs_n \geq 0,\ \forall \mathrm{n} \tag{56}$$

$$-Pd_n + MP_z + Rd_n - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n} \leq 0} \cdot Rfl_l^{up} + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n} \geq 0} \cdot Rfl_l^{lo} \geq 0 \perp Xd_n \geq 0,\ \forall \mathrm{n} \tag{57}$$

$$-MP_{z'} + MP_z + PPd^{+}_{e(z,z')} \geq 0 \perp PPd^{+}_{e(z,z')} \geq 0, \forall e \tag{58}$$

$$+MP_{z'} - MP_z + PPd^{-}_{e(z,z')} \geq 0 \perp PPd^{-}_{e(z,z')} \geq 0, \forall e \tag{59}$$

$$-MP_{z'} + MP_z + PPd^{+}_{e(z,z')} \geq 0 \perp EX^{+}_{e(z,z')} \geq 0, \forall e \tag{60}$$

$$+MP_{z'} - MP_z + PPd^{-}_{e(z,z')} \geq 0 \perp EX^{-}_{e(z,z')} \geq 0, \forall e \tag{61}$$

[0100] In case there exist additional linear constraints of type (40), then condition (56) is substituted by:

$$Ps_n - MP_z + Rs_n + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0} \cdot Rfl_l^{up} - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0} \cdot Rfl_l^{lo} + \sum_j a_{j,sn}\big|_{a_{j,sn}\geq 0} \cdot R_j - \sum_l a_{j,sn}\big|_{a_{j,sn}\leq 0} \cdot R_j \geq 0 \perp Xs_n \geq 0\,,\ \forall n \qquad (62)$$

and condition (57) is substituted by:

$$-Pd_n + MP_z + Rd_n - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0} \cdot Rfl_l^{up} + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0} \cdot Rfl_l^{lo} + \sum_j a_{j,dn}\big|_{a_{j,sdn}\geq 0} \cdot R_j - \sum_l a_{j,dn}\big|_{a_{j,dn}\leq 0} \cdot R_j \geq 0 \perp Xd_n \geq 0\,,\ \forall n \qquad (63)$$

[0101] The method resolves to a solution that determines:

1) a market clearing price for each bidding/exchange zone,
2) cleared supply energy volumes, to be injected in each node, with supply offer prices that are lower than or equal to the corresponding bidding/exchange zone clearing price,
3) cleared demand energy volumes, to be absorbed in each node, with demand bid prices that are higher than or equal to the corresponding bidding/exchange zone clearing price,
4) transmission line flows between nodes that are lower than or equal to the respective flow limit,
5) energy exchange volumes to be transferred between bidding/exchange zones, with direction from a bidding/exchange zone with a lower clearing price to a bidding/exchange zone with a higher clearing price,
6) energy balance at nodal level, implicitly attained through the use of PTDFs, and
7) energy balance at bidding/exchange zone level, consistent with corresponding nodal net energy injections of nodes included within the bidding/exchange zone, and energy exchanges with all interconnected bidding/exchange zones.

[0102] The presented solution method thus results in a model that is both theoretically and practically efficient in terms of social surplus and cleared intuitive exchanges.

[0103] The proposed method attains a simultaneously physically feasible and commercially rational solution, satisfying the "fairness" and "rationality" requirement of market designers and participants in terms of intuitive commercial exchanges [9].

[0104] The solution method according to this invention presented herein can thus be formulated as a mathematical programming model, e.g. as a Mixed Complementarity Problem, comprising linear complementarity conditions of the associated quantity and price variables, or e.g. as a Quadratic Programming problem, that can be solved either by commercially available solvers or by tailed-made solvers/algorithms.

[0105] The embodiments of the present invention are suitable for the clearing of electricity markets with a hybrid network configuration, namely nodal-based configuration for congestion management in network branches, and inter-zonal configuration for the commercial exchanges between interconnected bidding zones, as shown in Fig. 3.

[0106] The present invention concerns nodal-based -cf. portfolio-based- offers/bids by the market participants, therefore it is suitable for markets with unit-based bidding rules -cf. portfolio-based bidding-. Thus, the European markets after reformed appropriately -to apply unit-based bidding- may employ directly the present invention, underlying its industrial applicability.

[0107] As compared with the traditional "intuitive patch" applied in CWE, the conditions of the presented model guarantee that all physical flows will be retained to their limits -and not artificially to tighter limits, as in the said "intuitive patch"- and zonal injections will be distributed in internal nodes dynamically, in a non-static way. This constitutes the main enhancement of the proposed solution method with respect to the currently applied "intuitive patch" [3] which has been incorporated in EUPHEMIA [14], the day-ahead market solver in Europe.

Basic nomenclature

Indices and Sets

[0108]

n Index of system nodes

$n(z)$ Index of system nodes within bidding zone z
z Index of bidding zones
e Index of exchanges between interconnected bidding zones
$e(z,z')$ Exchange from bidding zone z to bidding zone z'
l Index of transmission lines (branches)
$l(n,n')$ Transmission line (branch) connecting nodes n and n'

Parameters

[0109] Qs_n, Ps_n Supply offer volume and price in node n, in MWh and €/MWh, respectively
Qd_n, Pd_n Demand bid volume and price in node n, in MWh and €/MWh, respectively
FL_l^{up}, FL_l^{lo} Upper (positive value) and lower (negative value) remaining physical flow limits of line l, in MW, respectively; these limits are also called "Remaining Available Margin" (RAM) in flow-based modeling terminology
$ZIM_{e,z}$ Exchange / zone incident matrix, denoting a positive (value = 1) and negative (value = -1) exchange e transacted from/to bidding zone z, respectively; all remaining values of row e are equal to zero
$PTDF_{l,n}$ Power Transfer Distribution Factor of flow in branch l with respect to a nodal injection in node n and a withdrawal in the system reference node. The PDTF matrix satisfies the energy balance at each node, i.e. the node net energy injection (positive or negative) is equal to the algebraic sum of energy flows from and to the connected (neighboring) nodes.
ATC_e^{up}, ATC_e^{lo} upper and lower exchange limits (Available Transfer Capacities) for exchange e, in MW, respectively
$GSK_{z,n}$ Generation Shift Key of node n with respect to bidding zone z

Main Variables

[0110] Xs_n Supply volume in node n, in MWh
Xd_n Demand volume in node n, in MWh
$EX_e \in \mathbb{R}$ Volume of exchange e, in MWh
Rs_n, Rd_n Complement (dual) variable of supply and demand maximum volume constraints in node n, respectively, in €/MWh
Rfl_l^{up}, Rfl_l^{lo} Complement (dual) variables of line upper and lower flow limit constraints, respectively, in €/MW
Rex_e^{up}, Rex_e^{lo} Complement (dual) variables of exchange e upper and lower limit constraints, respectively, in €/MWh.

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Claims

1. A method used for processing bids that are submitted by market participants in an auction for electricity market commodities, **characterized in that** it comprises the following steps:

   - retrieving model parameters and bid data for the electricity market commodities;
   - applying the model parameters and bid data to equations representative of an electricity market, the equations including at least one variable to be determined;
   - simultaneously solving the equations for at least one variable, said solving being performed iteratively or in one shot to determine at least one variable and
   - publishing results of the auction to notify the market participants,

   particularly wherein said publishing includes solutions of the at least one variable of quantities and/or clearing prices for the electricity market commodities.

2. The method according to claim 1 for conducting an auction for an electricity market, **characterized in that** it comprises the steps of:

   - opening a data collection process of the auction of the electricity market to receive bids on electricity market commodities from market participants;
   - receiving the bids on the electricity market commodities;
   - closing the data collection process of the auction of the electricity market; and
   - simultaneously processing the bids to determine results for the electricity market; particularly wherein it further comprises validating the bids for the electricity market and publishing the results of the auction respectively, more particularly wherein said publishing includes at least one of the following actions:
   - posting the results of the computation on an electronic media; and
   - communicating the results to the market participants via an electronic communication; more particularly wherein the posted results include public information accessible by market participants;

   yet more particularly wherein the electronically communicated results include private information, and/or wherein the electronic communication includes at least one of the following means: e-mail, text messaging, and facsimile.

3. The method according to one of the claims 1 or 2 for participating in an electricity market auction conducted by a market operator for market participants, **characterized in that** it further comprises the steps of:

- establishing a communication link by a market participant with a market operator;
- communicating a bid for electricity market commodities from the market participant to the market operator; and
- receiving results of the auction from the market operator by the market participant, the results being generated simultaneously;

particularly wherein the results of the auction are received via an electronic communication means, more particularly wherein said receiving step includes: accessing a network location; and entering a password at said network location to receive the results, and/or wherein the results of the auction are published on a publicly accessible location.

4. The method according to any one of the claims 1 to 3, **characterized in that**

- said solving computes and/or said auction results include at least one of the following items: scheduled quantities, and/or exchange quantities, and/or clearing prices for the electricity market commodities, and power flow transmission usage;
- wherein said publishing includes posting solution of at least one variable of scheduled quantities, and/or exchange quantities, and/or clearing prices for the electricity market commodities;
- wherein said method further comprises matching the bid data, of scheduled quantities, and/or exchange quantities, and/or clearing prices to power grid locations, wherein said power grid location represents at least one of the following items: a power system bus, a power system node, a power system zone, a group or arbitrary number of buses or nodes or zones;
- wherein a market participant submits a bid including a set of points defining a price and quantity curve for electricity market commodities;
- wherein the bids for the electricity market include at least one-time interval for electric market commodities;
- wherein said process or solving includes performing an optimization or computation process;
- wherein the optimization or computation process includes solving iteratively or in one-shot a set of necessary variables and conditions included in a set of simultaneous equations;
- wherein process or solving is executed for multiple time intervals, either altogether or separately; and
- wherein process or solving is performed after an acceptance time for new bids and bid modifications.

5. Method according to any one of the claims 1 to 4 for the computation of the power flow in an electricity network and congestion management of the power flows in the electricity network under exchanges rules, wherein the electricity network comprises at least one of the following items:

a) a plurality of nodes of a physical electricity network;
b) a plurality of transmission lines interconnecting said network nodes, wherein a line energy physical flow is constrained by an upper limit, where said energy physical flow is defined as a linear function of nodal energy injections, where said nodal energy injection is defined as energy injected minus energy absorbed in the respective node;
c) a plurality of electricity exchange zones that group an arbitrary number of nodes;
d) a plurality of energy exchanges transacted between interconnected zones;
e) a plurality of supply orders for an energy injection at least in one node; and
f) a plurality of demand orders for energy absorption at least in one node,

characterized in that at least one of the following actions is performed:

- determining an electricity exchange system clearing signal for the said electricity exchange zones;
- determining the schedule of supply energy volumes to be injected in each node, with supply order thresholds that are lower than or equal to the corresponding electricity exchange zone clearing signal;
- determining the schedule of demand energy volumes to be absorbed in each node, with demand order thresholds that are higher than or equal to the corresponding electricity exchange zone clearing signal;
- determining the transmission line flows lower than or equal to the respective flow limit;
- determining the energy exchange volumes to be transferred between electricity exchange zones, with direction from an electricity exchange zone with a lower clearing signal to an electricity exchange zone with a higher clearing signal;
- making an electricity exchange zone energy balance of corresponding nodal net energy injections of nodes included within the electricity exchange zone, and energy exchanges with all interconnected electricity exchange zones.

6. Method according to claim 5, **characterized in that** it comprises in the clearing condition of nodal supply orders only positive terms with respect to the contribution of nodal supply injection to transmission line flows, i.e. positive PTDFs with respect to the transmission line flow upper limit on the one hand, and negative PTDFs with respect to the transmission line flow lower limit, on the other hand, wherein the clearing condition of supply orders in node (n) comprises at least a formulation as follows:

$$Ps_n - MP_z + Rs_n + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0} \cdot Rfl_l^{up} - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0} \cdot Rfl_l^{lo} + \sum_j a_{j,sn}\big|_{a_{j,sn}\geq 0} \cdot R_j - \sum_l a_{j,sn}\big|_{a_{j,sn}\leq 0} \cdot R_j \geq 0 \perp Xs_n \geq 0, \forall n \quad (62)$$

in particular where in this condition the variable Rs_n is defined by the condition

$$Xs_n \leq Qs_n \perp Rs_n \geq 0, \ \forall n \quad (51)$$

and/or **in that** it comprises in the clearing condition of nodal demand orders only positive terms with respect to the contribution of nodal demand absorption to transmission line flows, consisting of positive PTDFs with respect to the transmission line flow lower limit, on the one hand, and negative PTDFs with respect to the transmission line flow upper limit, on the other hand, wherein the clearing condition of demand orders in node *(n)* comprises at least a formulation as follows:

$$-Pd_n + MP_z + Rd_n - \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\leq 0} \cdot Rfl_l^{up} + \sum_l PTDF_{l,n}\big|_{PTDF_{l,n}\geq 0} \cdot Rfl_l^{lo} + \sum_j a_{j,dn}\big|_{a_{j,dn}\geq 0} \cdot R_j - \sum_l a_{j,dn}\big|_{a_{j,dn}\leq 0} \cdot R_j \geq 0 \perp Xd_n \geq 0, \forall n \quad (63)$$

in particular where in this condition the variable Rd_n is defined by the condition

$$Xd_n \leq Qd_n \perp Rd_n \geq 0, \ \forall n \quad (52)$$

and/or **in that** in said conditions, Rfl_l^{up} is defined by condition

$$\sum_n PTDF_{l,n} \cdot (Xs_n - Xd_n) \leq FL_l^{up} \perp Rfl_l^{up} \geq 0 \, \forall \, l \quad (53)$$

and Rfl_l^{lo} is defined by condition:

$$\sum_n PTDF_{l,n} \cdot (Xs_n - Xd_n) \geq FL_l^{lo} \perp Rfl_l^{lo} \geq 0, \ \forall \, l \quad (54)$$

and R_j is defined by condition:

$$b_j - \sum_{sn} a_{j,sn} \cdot Xs_n - \sum_{dn} a_{j,dn} \cdot Xd_n - \sum_{sn} a_{j,u} \cdot X_u \geq 0 \perp R_j \geq 0 \quad (40.b)$$

and/or **in that** the clearing condition of an inter-zonal exchange *(e)* comprises at least a formulation as follows:

$$-MP_{z'} + MP_z + PPd_{e(z,z')}^{+} \geq 0 \perp PPd_{e(z,z')}^{+} \geq 0, \ \forall e \quad (58)$$

$$+MP_{z'} - MP_z + PPd^{-}_{e(z,z')} \geq 0 \perp PPd^{-}_{e(z,z')} \geq 0\,,\ \forall e \qquad (59)$$

$$-MP_{z'} + MP_z + PPd^{+}_{e(z,z')} \geq 0 \perp EX^{+}_{e(z,z')} \geq 0\,,\ \forall e \qquad (60)$$

$$+MP_{z'} - MP_z + PPd^{-}_{e(z,z')} \geq 0 \perp EX^{-}_{e(z,z')} \geq 0\,,\ \forall e. \qquad (61)$$

7. Method according to claim 6, **characterized in that** said variable MP_z is defined as the electricity exchange zone clearing signal, and wherein the energy balance constraint of zone (z) is defined as:

$$\sum_{n(z)}(Xs_n - Xd_n) - \sum_e\left(ZIM_{e,z} \cdot EX_e\right) = 0 \ \perp MP_z, \forall z\,. \qquad (55)$$

8. Evaluation method according to one of the claims 1 to 7, **characterized in that** said electricity exchange system is allocated to a market, wherein said electricity exchange zones consist of bidding zones, further wherein said clearing signal is assigned to a clearing price, and further wherein said orders represent offers and bids.

9. A system for processing bids by electricity market participants of an auction for electricity market commodities, particularly for carrying out the method as defined according to one of the claims 1 to 8, **characterized in that** it comprises:

a database including model parameters and bid data, wherein the model parameters and bid data are applied to equations representative of the electricity market, and wherein the equations include at least one variable to be determined;
a processor coupled to said database, wherein the processor is arranged for simultaneously solving the equations for at least one variable to be determined, wherein said solving is performed iteratively to determine at least one variable according to a predetermined objective or criteria; and
means for publishing auction results to notify the electricity market participants where a publishing mean executes at least one of the following actions:

posting solutions of at least one variable on an electronic media for the participants to retrieve and electronically communicating the solution for at least one variable to the electricity market participants;
and/or wherein said publishing includes at least posting and electronically communicating solution of at least one variable.

10. The system according to claim 9 for conducting an auction for an electricity market, **characterized in that** it comprises:

- a computer server coupled to a communication network, said computer server operating the electricity market;
- a plurality of electronic devices coupled to the communication network, wherein said electronic devices are in communication with said computer server for submitting bids for electricity market commodities;
- and at least one database coupled to said computer server, wherein said at least one database stores the submitted bids, power grid model parameters, and electricity market parameters, wherein said computer server simultaneously processes the submitted bids to determine the auction results;

particularly wherein said electronic devices include at least one of the following elements: computer, facsimile, telephone, and personal communication device, or/and wherein said computer server further publishes the results of the auction available to said electronic devices, wherein the publishing of the results includes at least one of the following items: posting on the communication network and electronically transmitting.

11. The system according to any one of the claims 9 or 10, **characterized in that** it includes a computer-readable medium, having stored thereon sequences of instructions, the sequences of instructions including instructions, when executed by a processor, causing the processor to:

- retrieve modeling parameters and a plurality of bids for electricity market commodities;
- apply the modeling parameters and bids to equations representative of an electricity market, wherein the

equations include at least one variable to be determined;
- solve the equations for at least one variable, wherein said solving is performed iteratively to determine the at least one variable according to a predetermined objective or criteria;
- and publish results of the auction to notify the market participants;

and/or **in that** it includes a computer-readable medium, having stored thereon sequences of instructions, wherein the sequences of instructions include instructions that, when executed by a processor, cause the processor to:

- establish a communication link by a market participant with a market operator;
- communicate a bid for electricity market commodities from the market participant to the market operator; and
- receive results of the auction from the market operator by the market participant, the results being simultaneously generated.

12. The system according to any one of the claims 9 to 11, **characterized in that** it includes at least one computer programmed to execute a process for participating in an electricity market in which a computer server operated by a market operator conducts an auction for electricity market commodities, wherein the process comprises the following steps of:

- transmitting electronic signals to establish a communication link between a market participant computer and the computer server;
- generating at least one bid for the electricity market commodities; and
- causing electronic signals representing at least one bid to be sent to the computer server for submission of at least one bid to be submitted to the auction, the bids being simultaneously processed to determine results of the auction;

particularly wherein the process further comprises the steps of determining results of the auction based on at least one bid and causing electronic signals representing the results of the auction to be sent from the computer server to the market participant computer.

13. The system according to any one of the claims 9 to 12, **characterized in that** it includes at least one computer programmed to process bids submitted by market participants for electricity market commodities, wherein the process comprises:

- receiving means for receiving electronic signals representing electricity market model parameters;
- receiving means for receiving electronic signals representing the bids submitted by the market participants;
- applying the electricity market model parameters and bids to equations representative of an electricity market, and including at least one variable to be determined;
- iteratively computing solutions to at least one variable until the at least one variable satisfies a predetermined objective or criteria;
- determining results of the auction based on the at least one variable being determined; and
- transmitting electronic signals representing the results of the auction to be sent to publish the results of the auction;

particularly wherein the results of auction are published on an electronic network.

14. The system according to any one of the claims 9 to 13 for determining results of an auction conducted for electricity market commodities of an electricity market, **characterized in that** it comprises:

- means for storing model parameter and bid data;
- means for reading the model parameters and bid data from said means for storing;
- means for utilizing the model parameters and bid data to determine results of the auction; and
- means for publishing the results of the auction, with said means suitably interacting.

15. The system according to any one of the claims 9 to 14, **characterized in that** it involves an electricity market that constitutes one integrated electricity market or a set of coupled electricity markets, and comprises at least one of the following elements:

- a plurality of nodes of a physical electricity network;

- a plurality of transmission lines interconnecting said network nodes, wherein a line energy physical flow is constrained by an upper limit, where said energy physical flow is defined as a linear function of nodal energy injections, where said nodal energy injection is defined as energy injected minus energy absorbed in the respective node;
- a plurality of electricity exchange zones that group an arbitrary number of nodes;
- a plurality of energy exchanges transacted between interconnected zones;
- a plurality of supply bids, for an energy injection at least in one node; and
- a plurality of demand bids for energy absorption at least in one node,

wherein electricity market commodities include at least one of the following items electric energy, reserve capacity, and transmission capacity;
wherein said solving computes and/or the said auction results include, at least one of the following items: scheduled quantities, and/or exchange quantities, -and/or clearing prices for the electricity market commodities-, and power flow transmission usage;
wherein said publishing includes posting solution of at least one variable of scheduled quantities, and/or exchange quantities, and/or clearing prices for the electricity market commodities;
wherein said system further comprises matching the bid data, of scheduled quantities, and/or exchange quantities, and/or clearing prices to power grid locations, wherein power grid location represent at least one of the following items: a power system bus, a power system node, a power system zone, a group or arbitrary number of buses or nodes or zones;
wherein a market participant submits a bid including a set of points defining a price and quantity curve for electricity market commodities;
wherein the bids for the electricity market include at least one time interval for electric market commodities;
wherein said process or solving includes performing an optimization or computation process;
wherein the optimization or computation process includes solving iteratively or in one-shot a set of necessary variables and conditions included in a set of simultaneous equations; wherein process or solving, is executed for multiple time intervals, either altogether or separately; and
wherein process or solving, is performed after an acceptance time for new bids and bid modifications.

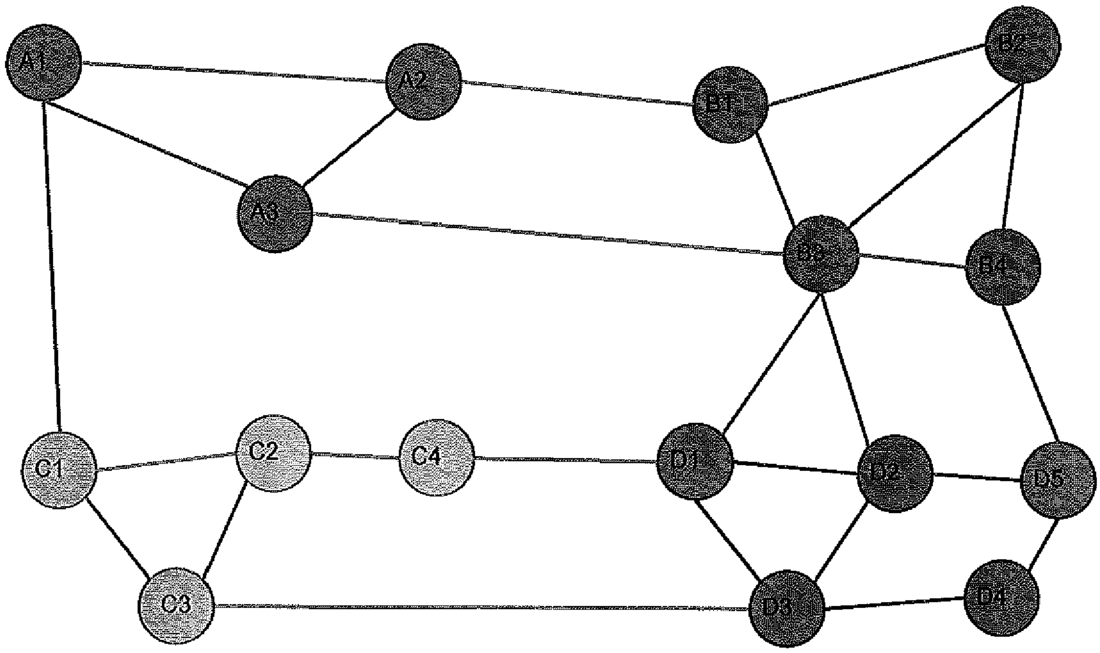


Figure 1

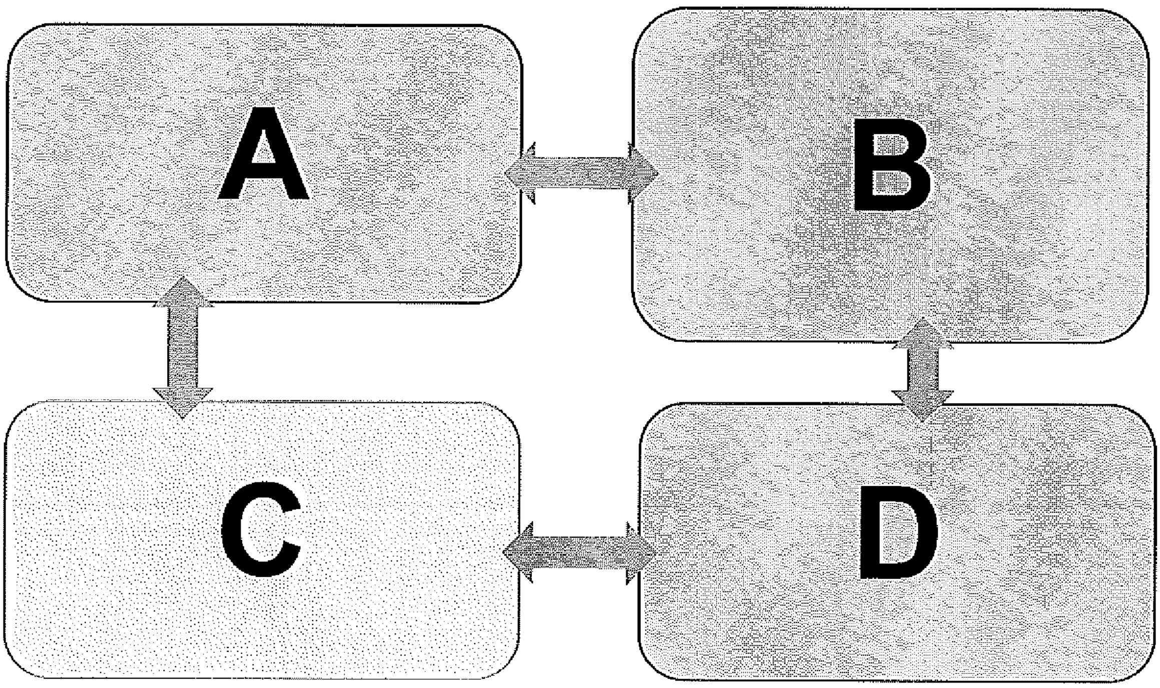


Figure 2

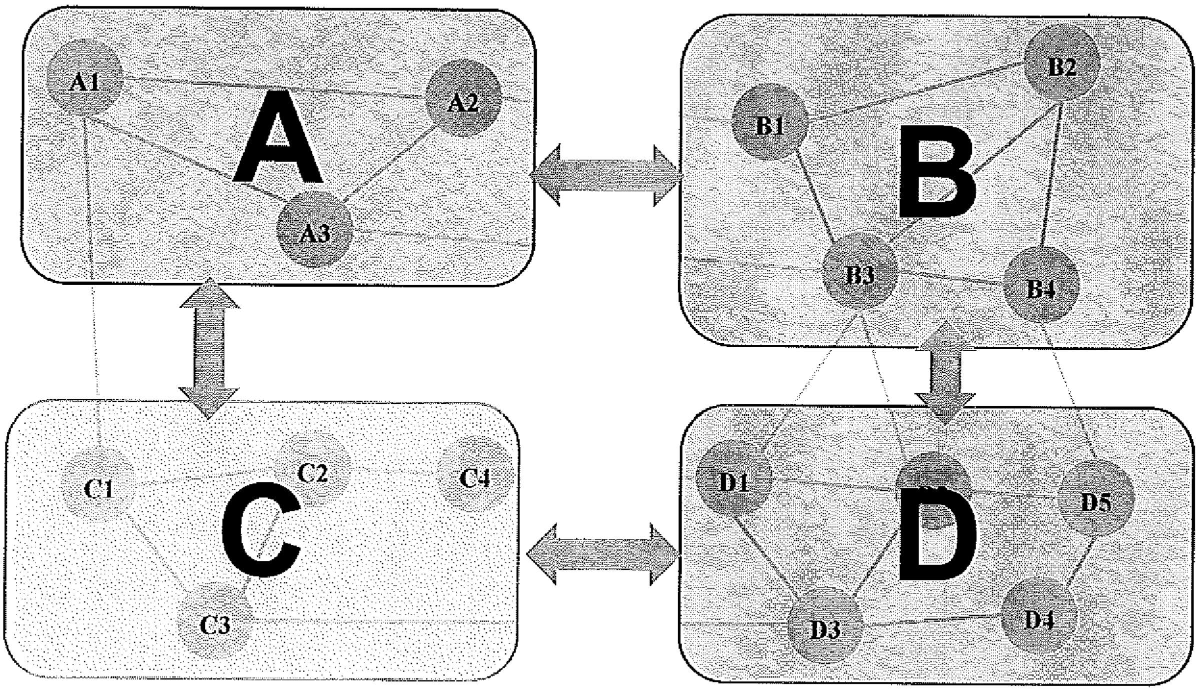


Figure 3

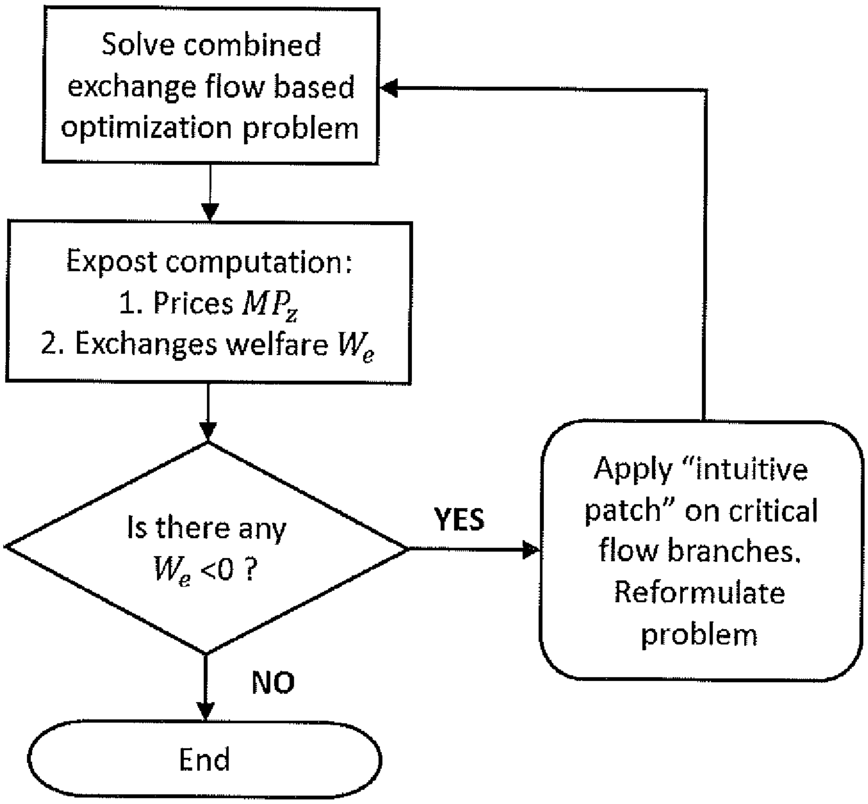


Figure 4

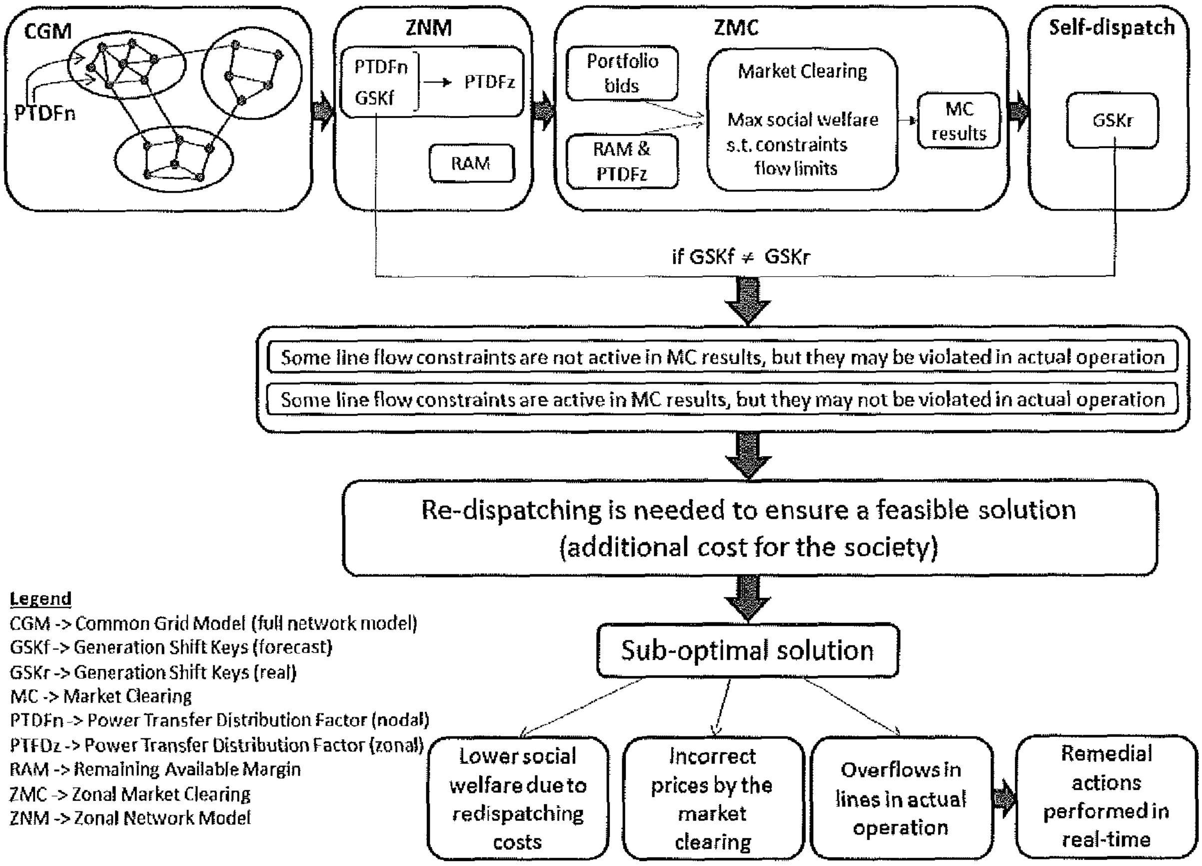


Figure 5

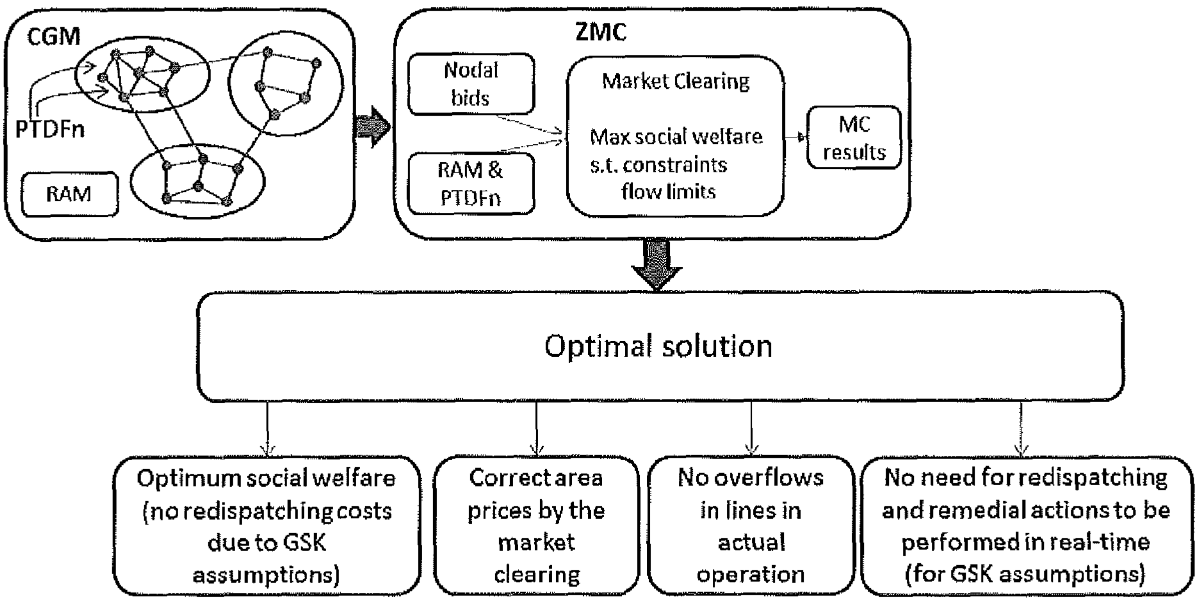
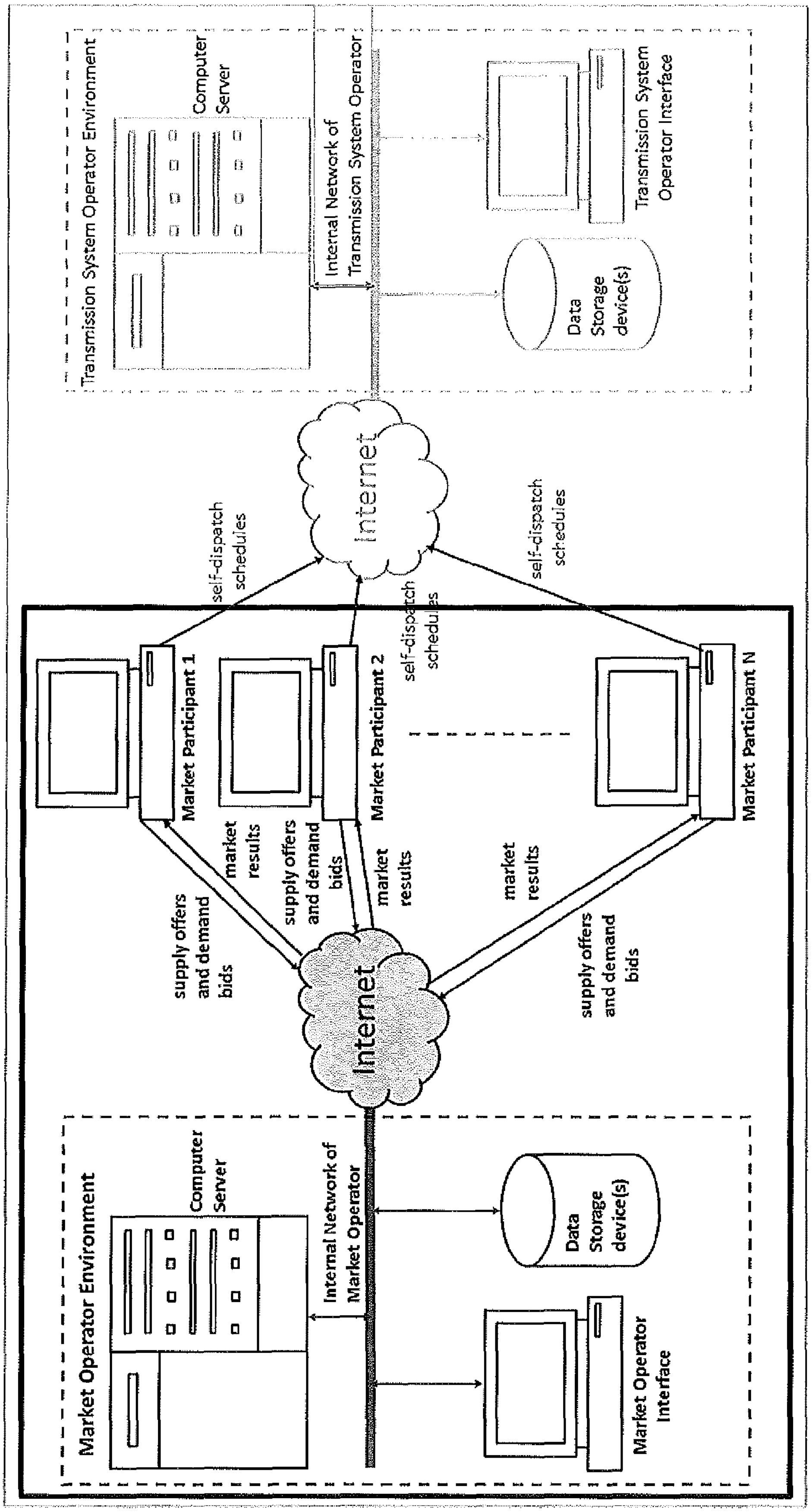


Figure 6

Figure 7


Transmission System Operator Environment
Computer Server
Internal Network of Transmission System Operator
Data Storage device(s)
Transmission System Operator Interface
Internet
self-dispatch schedules
self-dispatch schedules
self-dispatch schedules
Market Participant 1
Market Participant 2
Market Participant N
market results
supply offers and demand bids
market results
supply offers and demand bids
market results
supply offers and demand bids
Internet
Market Operator Environment
Computer Server
Internal Network of Market Operator
Data Storage device(s)
Market Operator Interface

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Application Number
EP 18 15 9586

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
	The claimed subject-matter, with due regard to the description and drawings in accordance with Art. 92 EPC, relates to processes comprised in the list of subject-matter and activities excluded from patentability under Art. 52(2) and (3) EPC. The information technology employed as an enabler for carrying out said processes is so well-known that its existence at the relevant date cannot reasonably be disputed. The claimed technical features, namely communication network with computer server, database and electronic devices and the use of electronic communications such as email, facsimile, telephone are therefore considered to be part of the notorious knowledge, for which no documentary evidence is deemed necessary (see Guidelines for Examination in the European Patent Office, B-VIII, 2.2.1). -----		INV. G06Q30/08
			TECHNICAL FIELDS SEARCHED (IPC)
			G06Q

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	17 May 2018	Streit, Stefan

CATEGORY OF CITED DOCUMENTS

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Non-patent literature cited in the description

- **A.G. VLACHOS ; P.N. BISKAS.** An Integrated Intuitive Exchange- and Flow-Based Market Clearing Model. *IEEE Transactions on Power Systems,* September 2016, vol. 31 (5 **[0111]**