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A COMPETITIVE SIMULATION PLATFORM FOR ELECTRICITY TRADING IN SMART GRIDS

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The work described in this paper was carried out at the Department of Telecommunications, Faculty of Electrical Engineering and Computing, University of Zagreb, under supervision of Assist. Prof. Vedran Podobnik, and is submitted to tender for Rector's award for the academic year 2011./2012.

Abbreviations

EU	*European Union*
DSM	*Demand Side Management*
ICT	*Information and Communications Technology*
EISA	*Energy Independence and Security Act*
NIST	*National Institute of Standards and Technology*
EEGI	*European Electricity Grid Initiative*
SET-PLAN	*Strategic Energy Technology Plan*
ENTSO-E	*European Network of Transmission System Operators for Electricity*
EDSO	*European Distribution System Operators for Smart Grids*
ETP	*European Technology Platform*
RD&D	*Research, Development and Demonstration*
EMCAS	*Electricity Market Complex Adaptive Systems Model*
MAIS	*Multi Agent Intelligent Simulator*
ACE	*Agent-based Computational Economics*
TAC	*Trading Agent Competition*
TAC AA	*Trading Agent Competition Ad Auctions*
TAC SCM	*Trading Agent Competition Supply Chain Management*
Power TAC	*Power Trading Agent Competition*
DU	*Distribution Utility*
Genco	*Generation Company*
JSF	*JavaServer Faces*
XHTML	*eXtensible HyperText Markup Language*
CSS	*Cascading Style Sheets*
URL	*Uniform Resource Locator*

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Introduction

The current electrical power systems are switching from a traditional grid to an advanced grid called smart grid. Changes that occur in the electricity sector will affect the way customers use electricity. It is believed that retail customers with smart metering equipment installed will be able to adjust their consumption habits, depending on a market price signal received from a smart grid. Thanks to new technological solutions, a user becomes an essential element in real-time alignment of energy demand and supply within the local area. In addition to technical aspects of smart grid, establishment of the retail electric energy market for supporting the market aspect of the smart grid systems is crucial. Consequently, what is lacking in addition to technical infrastructure of a smart grid is an efficient set of market mechanisms. In order to avoid bad market design once smart grids are going to be widely deployed, it is necessary to provide a risk-free environment for testing market regulative.

Power Trading Agent Competition (Power TAC) is an open, competitive market simulation platform that addresses the need for policy guidance based on robust research result on the structure and operation of retail electrical energy markets. The Power TAC is an international project created with the cooperation of six universities across Europe and North America, including the University of Zagreb. Responsibility of the University of Zagreb's team is to develop a visualization module for the Power TAC platform. Developed solution, presented in this paper, is not only scalable, robust and based on state-of-the-art technologies, but has a huge scientific value because it proposes a solution to seize dynamics of electric power markets through identifying, analysing and presenting stakeholders, processes and key interactions in a smart grid environment.

Motivation for transition from an existing, traditional electrical grid to a smart grid, the economic aspect of the smart grid as well as the review of possible approaches for market modelling is given in the first chapter. The second chapter contains general information about the Power TAC project and provides description of the Power TAC platform design. The technical aspect of the Power TAC platform is given in the third chapter. The last chapter describes a design of the Power TAC Visualizer, a visualization module for Power TAC platform, developed by University of Zagreb team.

1. Background and motivation

Energy has an extremely important role in shaping human life. Throughout the history man has used various types of energy to improve the quality of life: power of their own muscle was used for soil treatment; the strength of domestic animals was used for transporting people and goods; a fire for heating, food preparation, lighting and metalwork; wind to power windmills; water to power watermills; fire and water for steam engine; and ultimately electrical energy. Today, life without electrical energy is almost unimaginable, what makes it a highly significant form of energy.

According to Agenda 21 [1], the majority of world production and consumption occurs in ways that are not sustainable if overall consumption continues to grow and if application of the same technology is going be continued. Consequence of electric power production is the negative impact on the environment: air pollution with combustion emissions, radiation burden on environment, solid and liquid waste disposal, etc.

In order to support the concept of sustainable development[1], in terms of production it is necessary to improve existing technologies for electricity production based on the exploitation of coal, oil, gas and nuclear fuel and to implement technologies that rely on renewable energy sources in existing energy sector. The share of renewable energy sources in total consumption within the EU-27[2] in 2010 was 12.4% [2]. The European Union with document Europe 2020 [3] proposes the strategic goals that are focused to universal progress and to achieve the following energy targets by 2020: reduce CO2 emissions by 20% compared to the level of the year 1990, increase the share of renewable energy to 20%, and increase energy efficiency by 20%.

The introduction of renewable energy sources is a challenge to the existing traditional grid. The mode of transmission of electricity to end users as we know it, was not changed significantly since its first designs based on the idea of scientist Nikola Tesla in the year 1888

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[1] According to [25], s**ustainable development** is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

[2] **EU-27** - The European Union (EU) is an economic and political union of 27 member states.

[4]. Traditional power system (Figure 1) is designed as a centralized one-way transmission of electricity from producers to end consumers. Transmission of electricity is organized through high and medium-voltage networks to the low-voltage networks that enable energy delivery to end consumers.

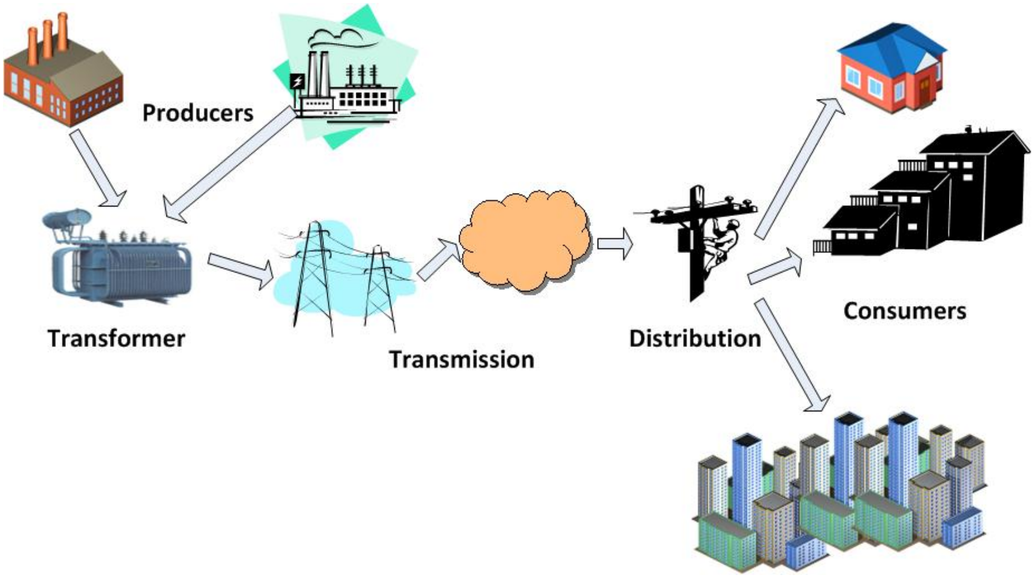

Figure 1: A traditional power system

Following problems can be identified from Figure 1:

- loss of energy due to big distances between producers and consumer, and
- centralized network topology.

A small number of control entities are responsible for managing the production capacity of several major power plants. Depending on the prediction of future demand, based on historical data on previously consumption, control entities schedule the available plants production.

The only form of renewable energy that is widely incorporated within a traditional power system is hydropower, used by hydroelectric power plants to produce electricity. In 2010, hydropower had the share in global electricity production of 16.1%, while other renewables, such as wind, geothermal, solar and biomass, accounted for only 3.3% [5]. The list of primary renewable energy sources as well as their various applications is depicted in Figure 2.

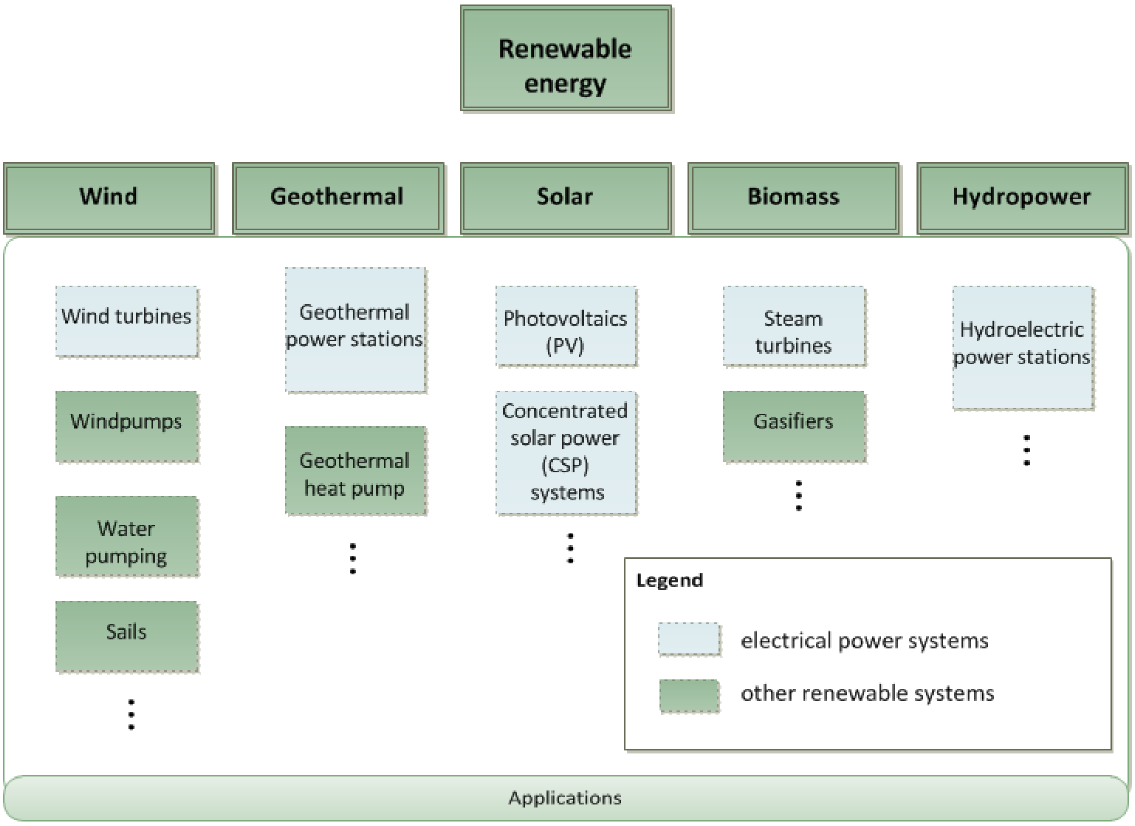

Figure 2: Various renewable energy sources

Some of the main characteristics of renewable energy sources are:

- their intermittent (due to variability of renewable energy sources) production, and
- their distribution in the network topology.

Wind power plants use power of wind what makes their contribution dependent on meteorological conditions. Solar cells are also dependent on the weather since it cannot produce electrical energy if there is not enough solar energy. Installation of numerous generators based on renewable energy sources like solar power and wind power, enriches network and contributes to its distribution. Renewable energy sources enable current customers to install their own generators, and consequently their participation in the electricity market in the additional role of producer. These characteristics also pose a problem for traditional electric power system, because there does not yet exist enough sophisticated management system that would adequately take into account the uncertainty in the production of a potentially large number of smaller plants. Another problem with the existing network infrastructure is inefficient operation during periods of peak demand[3] leading to poor quality services, particularly temporary failure of electricity networks.

In order to enable network infrastructure to handle many changes in the electrical system, it is necessary to introduce certain changes. One of proposed solution is to transform the existing power networks in advanced energy networks called *smart grids*.

According to the definition from the European Strategic deployment document [6], a smart grid is defined as “an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies”.

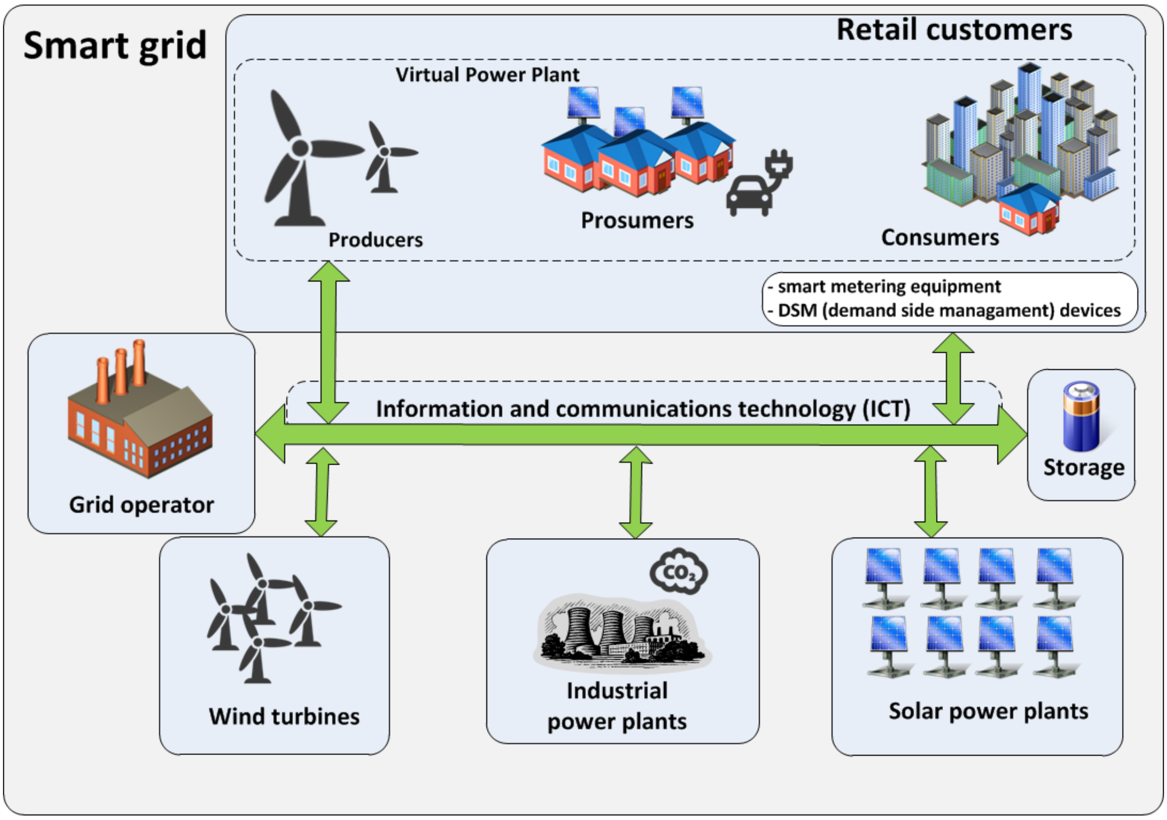

Figure 3: A smart grid deployment

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[3] **Peak demand** - Power consumption is not constant, but it depends on the characteristics of consumers. Peak demand occurs at a time when energy demand is very high. One of examples when it occurs is during summer months, when sudden increase in power demand is recorded due to switching on many cooling devices.

Example of an implementation of advanced energy networks at the local level is shown in Figure 3. In the given scenario, active entities of network topologies are:

- *grid operator*,
- *retail customers*,
- *storage*,
- *industrial power plants*, and
- various types of *renewables*.

Grid operator has the property of the regulated entity that oversees the overall operation of energy networks: i) managing the distribution of power; and ii) real-time balancing of supply and demand of energy.

Retail customers may be:

- *consumers* (such as office buildings or households),
- *producers* (such as privately-owned wind turbines or production-based households equipped with solar panels), or
- *prosumers*[4] (such as households or electrical vehicles).

In order to allow constant monitoring and managing their own load, retail customers are using devices such as smart metering equipment and demand side management (DSM) devices. Thanks to new technologies, that can increase their flexibility in spending the total power load forecasting, based on synthetic load profiles, is difficult. For the grid operator, management of retail customers is highly complex job. To allow for efficient control, retail customers are aggregated in the *virtual power plant*, thanks to software and smart-grid infrastructure. An example of a planned virtual power plant project is the four-year, €21 million EcoGrid project for the Danish island of Bornholm [7].

Storage serves to store excess energy produced, and enables the management of minor deviations in the system equilibrium. Power plants using fossil fuels and nuclear power plants

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[4] **Prosumer** is a portmanteau formed by contracting the word producer with the word consumer.

are examples of industrial power plants. Each of them brings different pollutants: combustion emissions of fossil and nuclear waste at nuclear power plants. Wind turbines and solar power plants, which all contribute to the intermittent production, were added in Figure 3 to emphasize the distribution of renewable power plants. They must be taken into account when balancing the whole network.

The introduction of information and communications technology (ICT) enables integration of the smart grid components and two-way communication between the entities. It is believed, the "Internet of energy" [8], will be developed due to use of ICT in energy distribution systems. This will serve as the basis for the development of advanced grid management, i.e. dealing with *energy layer* that includes production, transmission, distribution and consumption of energy. A smart grid extends a traditional power grid with various functionalities that are above the energy layer. Noticeable client-side functionalities are smart metering and demand-side management, while the grid operator can benefit from grid balancing and real-time monitoring of the grid. Multi-layered smart grid architecture along with its functionalities and correspondent flows is depicted in Figure 4.

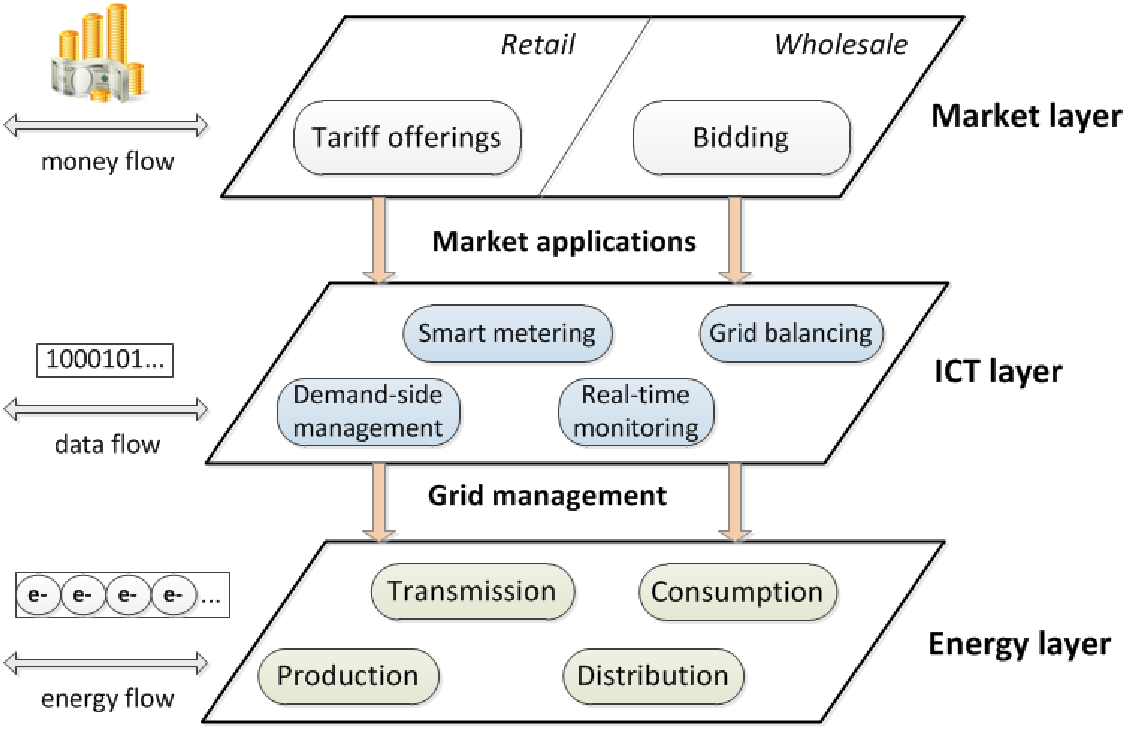

Figure 4: A multi-layered smart grid functional architecture

ICT layer provides the necessary infrastructure for wholesale and retail market applications and thus acts as a middleware between *energy* and *market layers* in smart grid architecture (Figure 4). The smart grid energy layer deals with the same activities as the traditional power grid although its implementation is far more complex. Production no longer ties to a couple of larger power plants; instead, it is consisted of numerous distributed energy sources. Limitations in transmission and distribution line capacity are now more critical, thanks to uncertainty in power production and consumption. Market layer consists of the *retail* and *wholesale* market. Retail customers use the extensive set of information provided by their ICT equipment to review and choose the appropriate tariff from the retail market offered by energy companies. The wholesale market represents a deregulated market that is used by competitive energy companies that want to obtain necessary capacity for their customers.

1.1. Smart grids

In the year 2007, United States prepared Energy Independence and Security Act (EISA) [9] with the aim of modernizing the transmission and distribution of electricity to the national level in order to achieve an advanced power grid. This act granted American National Institute of Standards and Technology (NIST) coordinating the development of accountability frameworks that includes protocols and model standards for information management to achieve interoperability[5] of smart grid devices and systems [10]. In February 2012, NIST publishes version 2.0 of document “NIST Framework and Roadmap for Smart Grid Interoperability Standards” [10], which specifies the progress made in developing smart grid backbone. NIST grouped its efforts into six key functional groups and put special attention on cyber-security and network communications mechanisms. Particular emphasis on the issue of demand response[6] and energy efficiency[7] from the user perspective was placed. The demand

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[5] **Interoperability** is the capability of two or more networks, systems, devices, applications, or components to interwork, and to exchange and readily use information—securely, effectively, and with little or no inconvenience to the user.

[6] **Demand response** is a mechanism to manage customer consumption of electricity in response to supply conditions, for example, having electricity customers reduce their consumption at critical times or in response to market prices.

response is used to optimize the balance between supply and demand of electricity. Thanks to increased information about energy consumption offered by new technology, consumers devoted towards energy efficiency are able to save energy, and potentially earn more if they manage to learn where it pays to invest further [10][11].

European Electricity Grid Initiative (EEGI) is an example of European industrial initiatives within Strategic Energy Technology Plan (SET-Plan). EEGI is a result of the industrial partners ENTSO-E[8], EDSO[9] and SmartGrids ETP[10]. The initiative proposes a nine-year program of research, development and demonstration (RD&D) that will encourage innovation and development of energy networks of the future in Europe. Implementation plan for the period from 2010 to 2012, and the guide for the period from 2010 to 2018 [12] describes the future solution as a user and market-oriented, interactive, reliable, flexible and sustainable electric power system. With a market point of view, the objectives of the initiative group EEGI include:

- active user participation in the electricity market,
- integration of national networks in the market-oriented European network, and
- opening of business opportunities and markets for new participants in the advanced energy networks [12].

1.2. Economic aspect of the smart grid

Previous chapters suggest there is a plan for implementing a technical infrastructure of a smart grid. Users of such networks will have at their disposal advanced equipment for

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[7] **Energy efficiency** is the goal of efforts to reduce the amount of energy required to provide products and services.

[8] **ENTSO-E (*European Network of Transmission System Operators for Electricity*)** - represents all electric TSOs in the EU and others connected to their networks, for all regions, and for all their technical and market issues (https://www.entsoe.eu/).

[9] **EDSO** (***European Distribution System Operators*** *for* ***Smart Grids*****)** is an international non-profit association committed to the development of Smart Grids in Europe. http://www.edsoforsmartgrids.eu/

[10] **SmartGrids ETP (*European Technology Platform*)** - is the key European forum for the crystallization of policy and technology research and development pathways for the smart grids sector, as well as the linking glue between EU-level related initiatives (http://www.smartgrids.eu/web/node/81).

recording energy consumption in real time, which are used to gain better control over their own consumption. Dynamic pricing of electricity, which reflects the state of energy balance on the market, motivates change in consumers’ energy spending pattern to reduce their own costs and improves delivery capacity of the producer [13]. This behaviour contributes to the additional complexity of the production and distribution of energy: they must operate in real time to maintain the load balance of power grids.

Thanks to new technological solutions, a user becomes an essential element in balancing supply and demand of energy within the local area. In addition to technical aspects of smart grid (i.e. energy and ICT layer in Figure 4), establishment of the retail electric energy market for supporting a market aspect of smart grid systems is crucial.

Another problem relates to the centralized and regulated electricity markets, which currently undergo a restructuring. California energy crisis in 2000 [14] is one example of unsuccessful deregulation of the electricity market. Some of the causes of the crisis in the California are market manipulation of California market stakeholders and the partial deregulation of energy market. The disintegration of the market in California has shown that the success of competitive electricity markets depends on the design of the market, demand response, reserve capacities, financial risk management, and reliable management of electricity supply chain [13].

1.3. Modelling smart grid markets

In order to identify and limit the problems of the electricity market, prior to its establishment, it is necessary to offer a simulation environment to test ideas about the design of electricity markets. Several modelling methods [15] can be used for modelling electricity markets:

- *equilibrium models*,
- *game theory*, and
- *human-subject research*.

However, all mentioned methods have some shortcomings.

First, *equilibrium models*, do not take into account the strategic behaviour of market participants, or assume that parties have all relevant information about the characteristics and behaviour of other participants. In addition, equilibrium models neglect the consequences of the knowledge that a participant could get through the daily operation on the electricity market.

Second, *game theory* is largely limited to the specific situation in the market that depends on a few factors, and thus achieves stringent, sometimes unreal assumption of behaviour of participants.

Third, employing *human-subject research* can be rather difficult to research related to the electricity market since it takes great expertise to describe the behaviour of electricity generators to market in a realistic manner.

A possible solution which addresses all listed issues of other methods is market modelling based on software agents[11]. The following section provides a brief overview of several electricity market models based on software agents.

1.3.1. Agent-based market modelling

Considering the complexity of the electricity sector, as well as developed competitive electricity market economies, there is a need to explore methods of modelling market. Modelling based on agents is a methodology that offers solutions to some of the problems that are typical for the traditional models. There are number [15] of systems and tools based on agents that assist in analysis and design of electricity markets.

First, the Electricity Market Complex Adaptive Systems Model (EMCAS) [16], is agent simulation of electricity markets, which describes the behaviour of producers and consumers in the electricity market, simulates the activities of the electricity system and calculates the electricity price for each hour and location within the transmission network. Electricity prices depend on demand, production costs, congestion of the transmission system, and external factors such as delays in production or disturbances in the system and strategies applied by the power company. The EMCAS model results contain information about the economic consequences for individual companies and consumer groups in different scenarios.

Second, the Multi Agent Intelligent Simulator (MAIS) [15] is a system based on agents for analysis and understanding of the dynamic changes in prices in the U.S. wholesale

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[11] A **software agent** is a software program that autonomously acts for a user or other program in a relationship of agency.

electricity market in the period before and during the energy crisis in California [16]. The proposed MAIS artificially generates commercial agents with different learning abilities and give them the bidding strategy, in order to simulate the California electricity market, applied during the crisis period in California's energy in 2001.

Third, software model of Agent-based Computational Economics (ACE), allows arithmetic study of economic processes that are modelled in dynamical systems with agents. In the ACE model, an agent is presented as an entity that consists of a set of data and computational behaviour in the arithmetically created world. Possible areas of research within the ACE [17] model include:

- understanding and evaluating of the market design,
- assessing interactions between automated markets and trading agents,
- development of rich environment for economic decision-making in research with human subjects as a subject of research, and
- proposing business policy based on expected market behaviour.

1.3.2. Agent-based simulation platforms

Although existing simulation models, tools and systems represent a useful tool to view many details about the activities of the market, they are usually limited in opportunities to participate in the consideration of different strategies of individual market participants [15]. Simulation platform that emphasizes competition of market participants can help to identify potential hazards and design flaws of the electricity market. The competitive approach proved successful in the study of numerous innovations [17] [18]. Trading agent competitions uses a multi-year competitive format for studying assembling and trading of travel packages (TAC Classic) [19], Supply Chain Management (TAC SCM) [20], trading with keywords in sponsored advertising (TAC AA) [21] and designing of market rules (TAC Market Design) [22]. A solution that combines market agents and the element of competition in the electricity market simulation platform is Power Trading Agent Competition[12] (Power TAC) [23].

Power TAC is an example of agent-based competition simulation platform designed to allow exploration of the retail electricity market. The main goal of the Power TAC is to give a

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[12] Power Trading Agent Competition official site: www.powertac.org.

complete overview of the possibilities and limitations of open markets to identify good practice and legislation necessary for the management of energy networks of the future that will include a variety of distributed resources [15]. The concept of the Power TAC relies on the role of intermediary that serves as an aggregator of supply and demand for energy, which embodies software agent market at the level of program implementation. Detailed overview of simulation, including activities of intermediaries and other entities of competition, is given in the following chapters.

2. Power Trading Agent Competition platform

Power TAC is a competitive simulation platform that models a free[13], retail-level electrical energy market. Competitors in such simulation are business entities or "brokers" that can fulfil the real-world role of energy retailers in smart grid environment. Their task is to provide energy services to customers through tariff offerings, and then manage their customer portfolio loads by trading in a wholesale market.

2.1. Project stakeholders

The Power TAC is an international project created in the cooperation of six universities across Europe and North America:

- Aristotle University of Thessaloniki (Greece),
- Carnegie Mellon University (Pennsylvania, United States),
- Delft University of Technology (Netherlands),
- University of Minnesota (Minnesota, United States),
- Rotterdam School of Management, Erasmus University (Netherlands),
- University of Zagreb (Croatia).

Responsibility of the University of Zagreb's team is to develop a visualization module (called Power TAC Visualizer) for the Power TAC platform. The Power TAC Visualizer is a crucial component for the success of the whole project because it has a twofold role:

- enables real-time observing of Power TAC competitions, and
- provides enhanced analysis of stakeholders' behaviour in the Power TAC market.

Therefore, developed Visualizer should not only be scalable, robust and based on state-of-the-art technologies, but also has a huge scientific value because it proposes a solution to seize

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[13] A **free market** is a market where prices are determined by supply and demand. Free markets contrast with controlled markets in which prices, supply or demand are directly controlled.

dynamics of electric power markets through identifying, analysing and presenting stakeholders, processes and key interactions in the smart grid environment.

Power TAC Partners

This project was created with the cooperation of the following affiliations:

Aristotle University of Thessaloniki

Carnegie Mellon University

Delft University of Technology

University of Minnesota

Rotterdam School of Management, Erasmus University

University of Zagreb

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Figure 5: Power TAC Partners, retrieved from Power TAC official web site[14]

2.2. Competition overview

The major elements of the Power TAC scenario are shown in Figure 6. The main element, a competitive trading agent, is a self-interested *broker* that aggregates energy supply and demand with the intent of earning a profit. Brokers must build a good-quality portfolio of *retail customers* by offering carefully designed tariffs through *tariff market*. Good-quality portfolio implies having tariff subscriptions that are profitable and can be real-time balanced. However, the consumption and production capacities broker has acquired through the tariff market will almost certainly cause imbalance in broker’s energy supply and demand. The energy imbalance has two negative impacts. First, it assists in imbalance of the whole power grid, causing serious problems in the power grid management and lowers the quality of

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[14] http://powertac.org/node/7

energy service. The second problem is less-than-attractive balancing fees broker has to pay to distribution utility for causing imbalance of the power grid. Because of that, a profit-oriented broker will tend to use strategies that will contribute to low energy imbalance. Additionally, to tackle these problems, brokers are encouraged to trade in the *wholesale market* by placing bids to acquire some extra capacity or to sell an energy excess by placing asks.

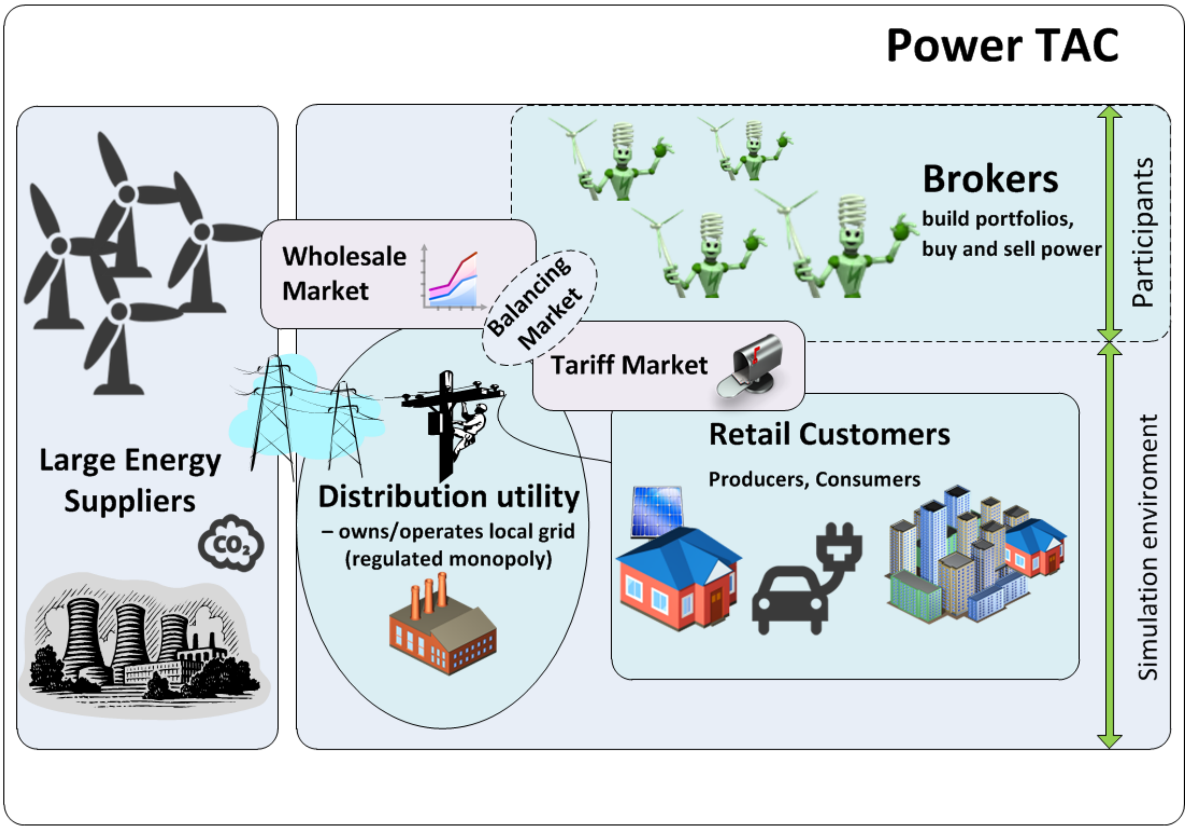

Figure 6: Major elements of the Power TAC scenario

Retail customers are essential entities connected to the grid. They can be *producers*, such as solar panels and wind turbines, *consumers*, such as offices, factories and private households or *prosumers*, such as electric vehicles and combined heat and power systems. Customers indirectly interact with brokers through tariff market or directly using individual contract negotiation process (latter option will be implemented for Power TAC 2013 competition). They have to choose the appropriate tariff by evaluating all available tariffs on the tariff market. Analysing meter readings provided by smart metering equipment, contract negotiating and providing the balancing capacities are some of tasks customers also do within this simulation. If specified in tariff contract from a broker, customers can allow balancing capabilities that are used by *distribution utility* in *balancing market* during the grid balancing process. The Distribution Utility (DU) represents the regulated electric utility and has the similar role as the grid operator from smart grid deployment (Figure 3). Except for grid balancing, the DU is also in charge of making distribution fees for brokers and providing default subscriptions for customers that are offered before competing brokers. In order to ensure liquidity to the wholesale market, *large energy suppliers* sell large-scale quantities of energy in the role of wholesale market participants. In the actual simulation, they are called Generation Companies (or *Gencos*). Finally, there is also a *wholesale buyer* (not shown in Figure 6) that simulates a population of buyers and speculators.

The time domain in Power TAC is managed by discrete time values called *timeslots*. Each timeslot represents 1 hour of competition time and is compressed to 5 seconds of real time. With the default game duration of 1440 timeslots (or 60 days), a typical simulation will run just over two hours of real time. The actual game duration will be randomized number of timeslots that is close to the game duration setting. This randomized game duration feature discourage broker developers in developing destructive and unrealistic strategies that would exploit the remaining market time.

Competition setting will also specify the number of competing brokers, i.e. groups of two, four or eight brokers, which can be varied for each simulation. Different group sizes serve to examine broker behaviours in different market positions, such as oligopolies[15], or high-competition markets.

2.2.1. Brokers

Broker, represented by a trading agent, is the main actor of the simulation. Figure 7 provides an overview of tasks brokers need to cope with in each timeslot. Typically, this is a three step process: *trading* in the wholesale market, *portfolio development* and *balancing* of energy supply and demand. An important fact is that the specific order of some activities is not as rigid as it is shown in Figure 7. Description of activities from the three step process can be found in the following chapters.

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[15] An **oligopoly** is a market form in which a market or industry is dominated by a small number of sellers (oligopolists).

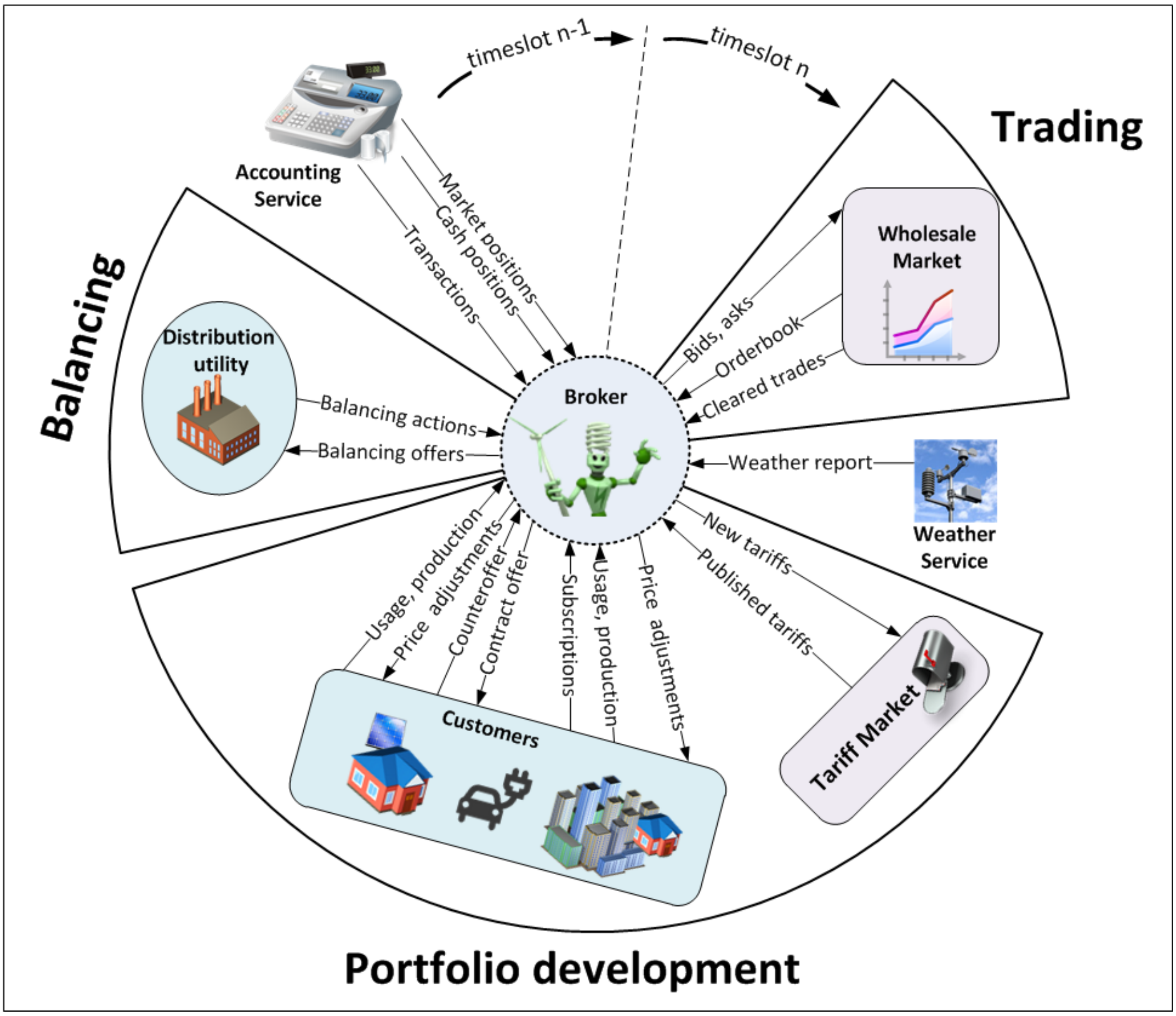

Figure 7: Power TAC broker's per timeslot activities

Portfolio management

To manage their portfolios in each timeslot, brokers may proceed with two parallel activities (Figure 8): *contract negotiation* and *tariff offering*. With contract negotiation, broker can try to make individual contracts with customers that do not want to use tariff-like contracts. The real life examples of such large customers are factories and large-sized enterprises. In parallel with individual contract negotiation, broker must develop a good-quality set of tariff subscriptions with customers who will sell or purchase energy through the use of tariff offerings. Brokers can design and offer new tariff specifications and update or withdraw an existing tariff by interacting with customers through tariff market. Power TAC platform provides customers with various consumption and production behaviours. Each customer type can have a distinct production and consumption logic, which is briefly addressed in chapter 2.2.2.

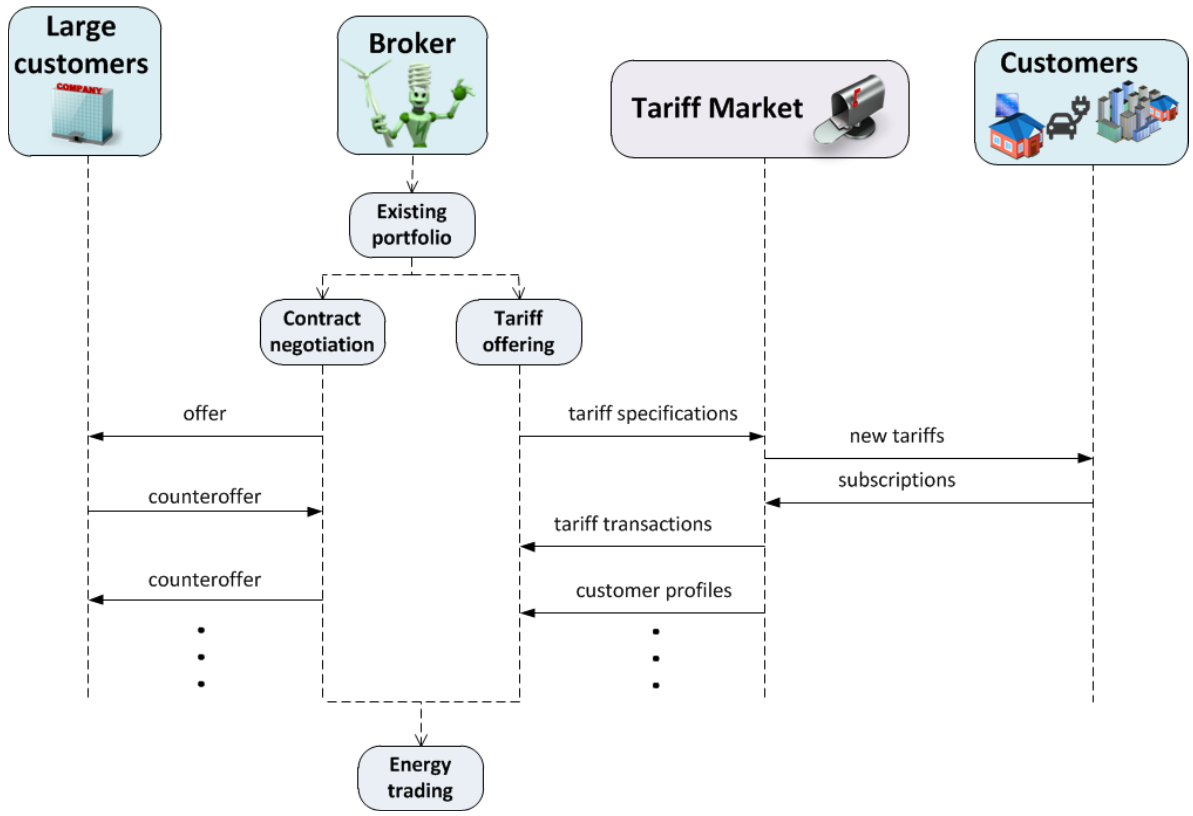

Figure 8: Portfolio management process: contract negotiation and tariff offering

Brokers can target a specific group of customers thanks to reasonably detailed tariff specification features, including:

- time related features, such as expiration date, minimum contract duration,
- rate specification, which enables the definition of time-of-use, weekday/weekend rates or tiered rates,
- two-part tariffs (fixed daily fee plus usage fee),
- balancing capacities offers, using variable rates with minimum and maximum values, estimated mean values, and notice intervals,
- signup fees or bonuses,
- early withdrawal penalties.

Before performing the actual interaction with the tariff market, a successful broker will need to estimate and reason about future consumer and producer behaviour. This will allow it to maintain a portfolio that is well-balanced and that assures an acceptable low risk of imbalance with acquired balancing capacities.

Energy supply and demand balancing

From broker’s point of view, an energy imbalance is rather undesirable state that is caused by numerous factors, including:

- imbalanced portfolio,
- variable power generation based on weather conditions, and
- other brokers’ strategies.

At the end of each timeslot, the distribution utility will charge broker with less-than-attractive balancing fee that is proportional to broker’s contribution in power grid imbalance. To minimize the DU final balancing charge calculated on the balancing market, a reasonable broker can use dynamic adjustment of prices for consumers and producers who are on variable-price tariffs or offer balancing capacities to the DU that were acquired through the period of portfolio management process. Dynamic prices are typically communicated to the customers some number of timeslots before the timeslot to which they apply. Because of that, brokers must have forecasting ability to determine the optimal prices to set for the target timeslot. In order to help setting up the optimal prices for future timeslots, broker’s forecasting module may try to predict demand and supply of customers. Broker can even try to forecast the prices in the wholesale market as well as the DU’s balancing market price.

Balancing capacities that can be offered to the DU during the period balancing process include:

- retail customers with interruptible consumption feature (such as households equipped with DSM devices),
- extra energy storage or extra on-demand energy production (such as bio-gas units).

Trading in the wholesale market

Other way to reduce energy imbalance is by trading in the wholesale market. The Power TAC platform implements the wholesale market in a periodic double auction format. Brokers can submit bids and asks to the wholesale market for delivery between one and 24 hour in the future.

The wholesale market will clear for each of the enabled timeslots when the simulation clock is advanced to a new timeslot. The clearing process will construct supply and demand curves from received bids and asks to determine the clearing price of each timeslot markets. The clearing price is the price that maximizes turnover and is set at the intersection of demand and supply curves.

2.2.2. Retail customers

Retail customers are models of numerous customer types, including electric vehicles, combined heat and power systems, solar panels, wind turbines, offices, factories and private households. Customer models ultimately represent the entities connected to the grid. They carry out tasks of choosing the appropriate tariff from the tariff market, contract negotiating for larger individual customers, recording meter readings for data analysis and optionally providing balancing capacities. Customer models are also designed to address responsiveness to price changes of customers in the real life applications. Each customer model is defined with one of the following power types:

- *consumption* – power flow from grid to customer,
- *interruptible consumption* – power flow from grid to customer that can be interrupted by the DU within certain bounds, typically characterized by heat-storage capacity,
- *production* – power flow from customer to grid; this power type is further split into subtypes that allow differentiation of power sources,
- *storage* – power flow to and from the grid; continuous operation in one direction is limited by storage capacity.

Tariff selection

Customers indirectly interact with brokers through tariff market or directly using individual contract negotiation process (latter option is not available yet). They are able to choose an appropriate tariff through periodic evaluation of the brokers' tariffs available on the tariff market. In order to evaluate listed tariffs, customer models need to derive the utility of each tariff u_i:

$$u_i = -(c_v + c_f)\alpha_{cost} - r_i\alpha_{risk} - I_i\alpha_{inertia} \quad (1)$$

Parameters α_{cost}, α_{risk} and α_{risk}, are customer-specific weighting parameters for tariff evaluation that deal with cost, risk and customer's inertia factor respectively. Variable tariff costs c_v are calculated using consumption payments: consumption payments are determined by sampling k random days, deriving each day's optimal consumption under the tariff to be evaluated and finally averaging the realized cost. For variable tariffs, this calculation is performed using the average realized values. Fixed tariff payments c_f consist of sign-up fees/bonuses of the new tariff $c_{sign-up}$, daily periodic payments c_{daily} as well as exit fees of current tariff c_{exit}. These costs are to be normalized to a one-day time span with the expected tariff life $\tilde{t}$ for the other payments. The normalized values of the fixed payments are summed to obtain the fixed other payments value:

$$c_f = c_{daily} + \frac{c_{sign-up} + c_{daily}}{\tilde{t}} \quad (2)$$

Tariff risk r_i is the risk of unfavorable rate developments under dynamic contract. It is evaluated using the variance of the realized prices. Finally, customer's behavioural cost of changing a tariff is defined as customer inertia I_i. This parameter has value of one for all tariffs except the current one; in that case, the value is zero.

The utility is an essential part of the customer tariff selection. However, an overall decision might not pick the highest utility tariff. Instead, a *logit choice model* is used to either mimic not perfectly rational tariff choice in case of single customer models or to assign population shares to different tariffs in case of a population customer model. Instead of providing a discrete tariff decision, a choice probability P_i is obtained for each tariff i from the set of tariffs considered $\mathbb{T}$:

$$\mathbb{P}_i = \frac{e^{\lambda u_i}}{\sum_{t \epsilon \mathbb{T}} e^{\lambda u_t}} \quad (3)$$

The parameter $\lambda \geq 0$ is a measure of how rationally a customer chooses tariffs: $\lambda = 0$ represents random, irrational choice, while $\lambda = 1$ represents perfectly rational customers always choosing the tariff with the highest utility.

The effect of tariff choice on realized load patterns

Customers are an integral part of the simulation. Their effect on the simulation is quantified by per-timeslot meter readings for both consumption and production. The actual outcome of timeslot metering may depend on the following group factors:

- *static factors* that include model primitives such as the number of household members, work shift hours and equipment. They create the base load profile that is independent of developments in the game,
- *broker-dependent factors* that are caused by broker actions, including the tariff (load shifting caused by time-of-use pricing) and balancing capability actions,
- *game-dependent factors* include the game environment factors such as randomization and weather conditions.

The effect of tariff choice on realized load patterns is the essential part of the Power TAC research setting. In order to provide different types of customer's load influence, multiple consumption and production logic were implemented, including *fully static, static amount with flexible timing*, *flexible amount with static timing* and *fully dynamic* logic.

First, *fully static* logic is characteristic for customers whose meter-readings are independent of their selected tariff. Examples of such customers may include rich or industrial customers that do not have shift load capabilities or treat electricity cost as insignificant part of their business.

Customers who will not change their consumption amount but are willing to change the timing of their loads are described with *static amount with flexible timing* logic. They will tend to minimize their cost by scheduling the activities appropriately.

Then, customers that have flexible amount with static timing use simple demand behaviour: they will not time-shift their load capacity but may reduce consumption if the electricity cost becomes more expensive. Such consumption logic is used to reflect the impact of synthetic load profiles and controllable generation with well-defined cost functions such as micro-CHP system[16].

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[16] **Micro-CHP (micro combined heat and power) system** is an extension of the now well established idea of cogeneration to the single/multi family home or small office building.

Finally, *fully dynamic* logic implies both flexible consumption amounts as well as flexible pricing. Bottom-up models that employ such consumption logic are taking into account prices and available income, while top-down models specify cross-price elasticity between timeslots [24].

Balancing capabilities

Some customers may have balancing capabilities and thus be involved in the real-time grid balancing process. Broker can acquire interruptible consumers by offering a tariff with interruptible consumption feature and use it to reduce its own supply and demand imbalance. Other option is to attract customers that have energy storage capacity, which is limited by discharge power and level of charge. The last retail option for grid balancing is the controllable micro generation units that can pledge an extra energy production, such as micro-CHPs and bio-gas units.

Implementation

From implementation point of view, retail customers are realized in the forms of plugins that instantiates a population of a customer type. That allows researchers to customize experiments and do the research about the specific consumer types by using only relevant customer models.

2.2.3. Distribution utility

The Distribution Utility (DU) represents the regulated electric utility and has the similar role as the grid operator from smart grid deployment (Figure 3). Within simulation, it deals with the range of different grid-operating activities:

1. It is a natural monopoly in charge of power distribution from the transmission grid to the customers. Consequently, it also makes distribution fees that brokers must pay, proportionally to the quantities of the net load their customers supply to the grid. In the real life, instead of natural monopoly, this can be a cooperative, a for-profit regulated corporation, or a government.
2. It is responsible for real-time distribution grid balancing, carried out on the balancing market. Consequently, it makes balancing fees for brokers, based on the supply/demand energy imbalance broker has at the end of each timeslot,

3. It simulates the electric utility in a non-competitive regulated tariff prior to market liberalization by offering default tariffs for energy consumption and production. In an actual simulation, distribution utility is represented as “default broker” that initially provides access to power for customers. The default tariffs also help in limiting the possible unfair profitability of brokers caused by overpriced tariffs.

3. Power Trading Agent Competition platform deployment

Power TAC is conceived as an annual competition between university research teams, following the successful examples of other competitions [17] [18] that have encouraged a number of innovations through the research work. Each year, research teams are preparing programming solutions for software agents that competes against the software agents of other research teams.

Schematic representation of a platform deployment is shown in Figure 9. From a technical point of view, the Power TAC platform is Java-based platform based on the *Spring framework*, deployed on a servlet container (such as Tomcat or Jetty servlet containers).

Power TAC competition entities were implemented in the form of independent configurable plugins. Since it performs multiple roles, distribution utility is represented with two plugins: the logic of market balancing was implemented in the *Distribution-utility* plugin, while its role as a default tariff provider was carried out in the *Default-broker* plugin. Generation companies, whose logic is based on interactions with a wholesale market, were modelled with the *Genco* plugin. Both Broker agents and generation companies are participating in a wholesale market, an entity represented by the *Auctioneer* plugin. The financial aspect of the competition and the logic of tariff market were implemented in the *Accounting* plugin. The behaviour of retail customers was implemented with the *Customer* plugin. Each customer plugin describes one customer model. This plugin feature allows users of the Power TAC platform to customize an experiment by excluding desired customer-specified models.

Simulator uses previously mentioned plugins to simulate the market aspect of a smart grid. To simulate the impact of weather conditions, the simulator fetches the weather forecast data from a remote *Weather data server*. The simulator also contains set of mechanisms for communication with brokers, which can be distributed over the Internet.

For the Power TAC platform there are several different groups of stakeholders with different needs. Competitive teams are preparing for the competition through their own empirical research on the Power TAC platform. They should be able to easily use the platform in order to configure an experiment and they need to have a rich data representation in order to analyse behaviour of brokers and markets. Administrator is a person responsible for management of the competition. The group of external *observers* includes market regulators, industry partners and project sponsors. Such group will benefit with a high-level overview of the competition.

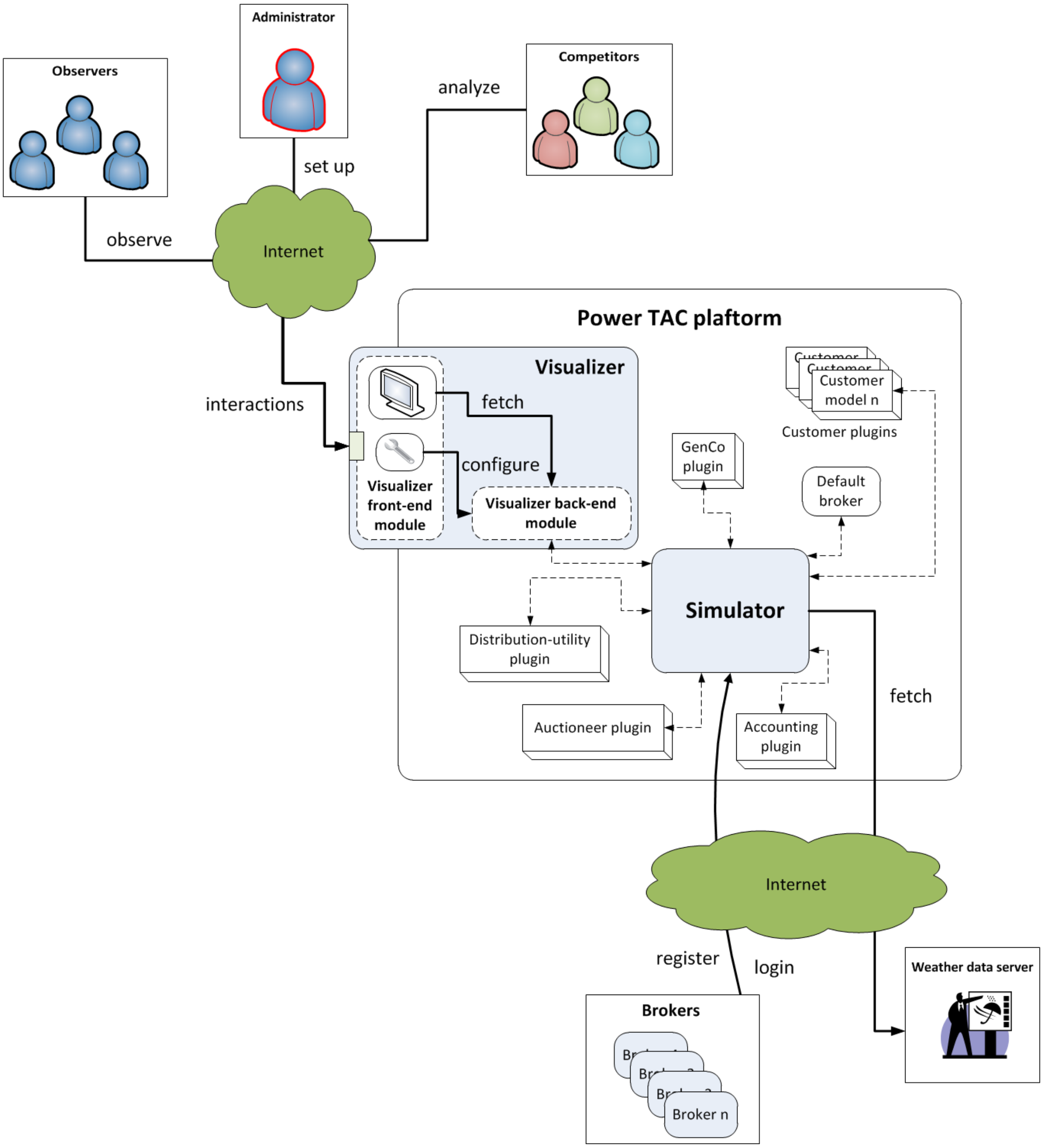

Figure 9: Power TAC platform deployment

To allow users interact with the platform, the Power TAC Visualizer is used. The Visualizer is a standard Power TAC component, implemented as a web-application. Bearing in mind the above user requirements, a special emphasis is placed on the visualization of the competition, as well as support for analysis of the competition. A detailed review of the Visualizer is given in the next chapter.

4. Power Trading Agent Competition Visualizer

The Power TAC Visualizer is a crucial component for the success of the whole Power TAC project because it has a twofold role:

- enables real-time observing of Power TAC competitions, and
- provides enhanced analysis of stakeholders' behaviour in the Power TAC market.

Therefore, developed Visualizer should not only be scalable, robust and based on state-of-the-art technologies, but also has a huge scientific value because it proposes a solution to seize dynamics of electric power markets through identifying, analysing and presenting stakeholders, processes and key interactions in the smart grid environment.

4.1. Technological groundings

The Visualizer consists of the two following modules as shown in Figure 10:

- *back-end module*, and
- *front-end module*.

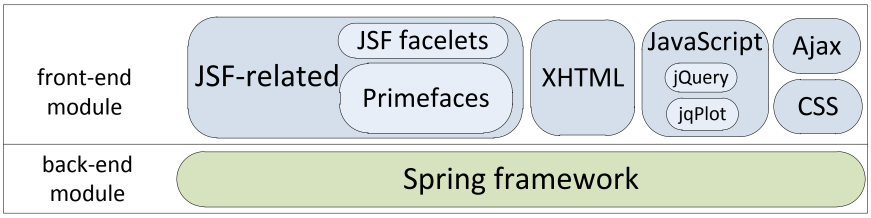

Figure 10: Technology stack for Visualizer's development

The main purpose of the back-end module is to interact with the simulator. Functionalities for the back-end module are implemented with the *Spring framework*[17], which is a Java-based technology.

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[17] The Spring Framework is an open source application framework and Inversion of Control container for the Java platform (http://www.springsource.org/).

The actual visualization of the Power TAC platform is achieved in the front-end module. In order to develop a rich user interface, the following two groups of technologies were used:

- *JavaServer Faces*[18] (JSF) technologies, and
- standard web technologies.

JSF technologies provide a server-side event model for dispatching events and attaching listeners to core system functionality. In particular, the Visualizer design exploits possibilities of a following set of JSF technologies:

- *JSF Facelets*[19] were used to build web-design template for the Visualizer,
- the rich set of components from the lightweight library *Primefaces*[20] is an important part of Visualizer's rich and visually attractive design.

A Visualizer's web-template is backed by a standard set of web technologies that are common in the web-design development:

- *EXtensible HyperText Markup Language* (XHTML) is one of the prerequisites for using *Facelets*. As a consequence, Visualizer has web-pages that are well-formed i.e. satisfy a list of syntax rules provided in the XHTML specification,
- Other than JSF-based *Primefaces* library, for a rich visual design, two JavaScript libraries were used. Graph data representation was achieved using the *jqPlot*[21]

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[18] **JSF** is a request-driven MVC web framework for constructing user interfaces using components (http://www.oracle.com/technetwork/java/javaee/javaserverfaces-139869.html).

[19] **Facelets** is an open source Web template system under the Apache license and the default view handler technology (aka view declaration language) for JavaServer Faces (JSF) (http://facelets.java.net/).

[20] **PrimeFaces** is an open source JSF component suite with various extensions (http://primefaces.org/).

[21] **jqPlot** is a plotting and charting plugin for the jQuery Javascript framework (http://www.jqplot.com/).

plotting library. Competition animations were implemented with a help of the *jQuery*[22] library,

- One of requirements for Visualizer is to provide a dynamic visualization. Manual page refresh is not a user-friendly solution. Therefore, an automatic mechanism for page update is needed. Such mechanism should only update relevant parts of a page to minimize the unnecessary network traffic load. A periodic partial page update is one of solutions for these requirements. To exercise such mechanism the Visualizer takes advantage of the *Asynchronous JavaScript and XML* (AJAX) technology,
- Visualizer's visual design is additionally stylized with the usage of custom-made *Cascading Style Sheets* (CSS).

4.2. Visualizer use-case scenarios

The main purpose of the Visualizer is to provide rich and intuitive display of relevant information about the Power TAC competition. This will help research community in evaluating market rules for policy guidance in the retail-level markets. Additionally, Visualizer as a multi-purpose web-application also provides the necessary infrastructure for competition management. This enables competitors to set up a custom experiment with various different parameters.

A high-level overview of interactions between actors and the Visualizer is shown in Figure 11. The Visualizer interacts with four different types of actors:

1. *Observer* is an actor that wants to observe the simulation. Observer is a casual user that does not require the Visualizer to have an advanced data-analysis features. Instead, Observer is more interested in visually attractive design and high-level overview of a running Power TAC competition. In the real life, such actors are researchers at an academic conference, market regulators, Power TAC project sponsors or industry partners.

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[22] **jQuery** is a cross-browser JavaScript library designed to simplify the client-side scripting of HTML (http://jquery.com/).

2. *Competitor* is an actor that provides a competing broker for the competition. In similar to Observer, Competitor demands visually attractive and rich design. What differs these two actors is Competitor's need for extensive data-analysis. Electricity market researcher involved in Power TAC project is a real-life example of this actor.
3. *Administrator* is an actor that is in charge of setting up the competition. Administrator wants to be able to configure competition options, to specify the list of brokers for a new competition and to run the competitive simulation. A game master is a real-life example of this actor.
4. *Simulator* is an actor that provides the competition. It is a simulation instance that communicates with the Visualizer by sending messages. The Visualizer uses these messages to create visualization of the competition.

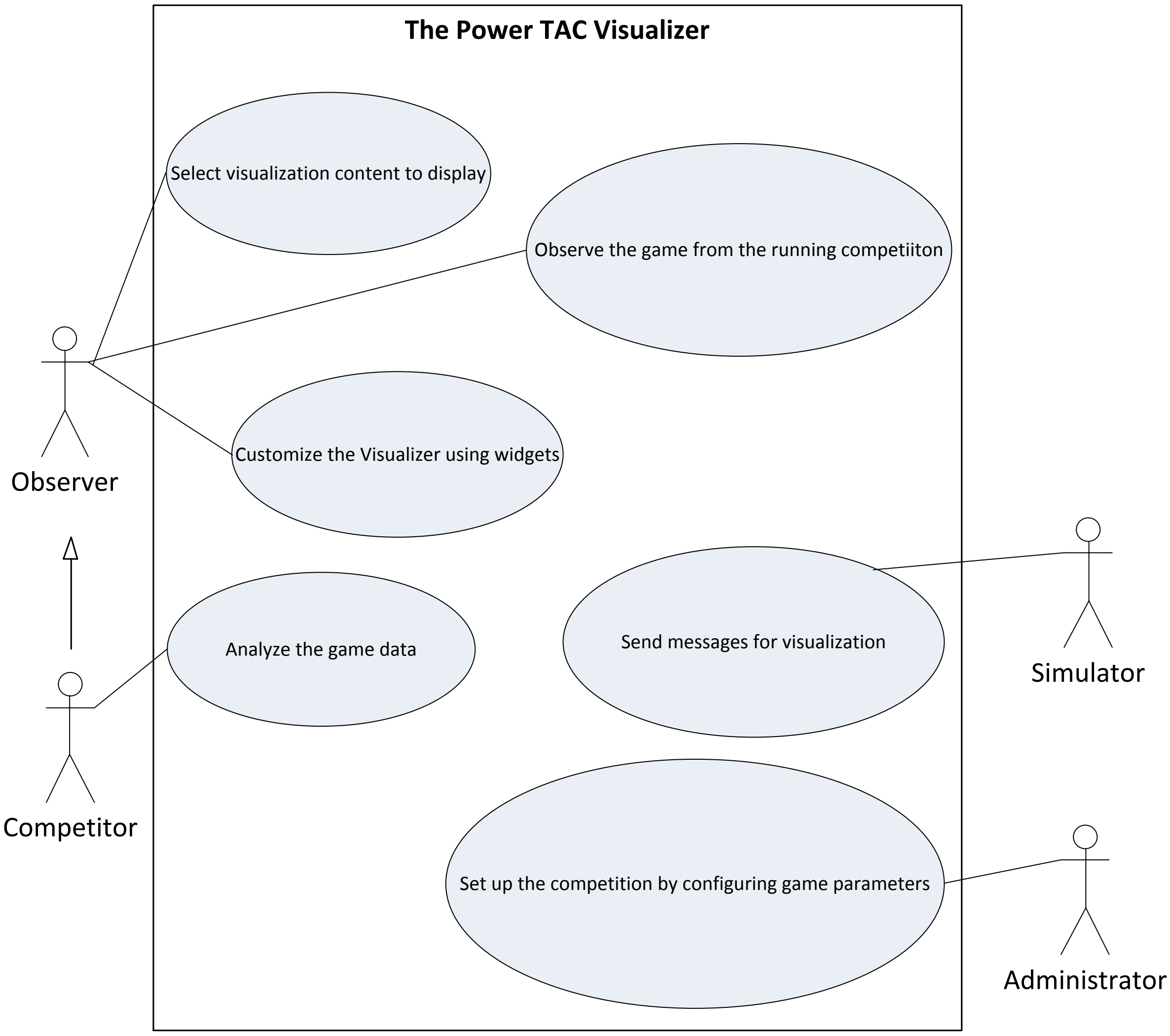


Figure 11: Use-case diagram – the Power TAC Visualizer

These four types of actors can be placed in a various use-case scenarios. The most important ones are described in the following chapters.

4.2.1. Use-case scenario (1): competition observing

The first use-case scenario describes a basic interaction between Observer actor and the Visualizer (Table 1). In order to be able access the Visualizer, Observer needs to have a web-browser and a valid Internet connection. Since Observer can use an arbitrary web-browser, a special emphasis was placed on cross-browser development of the Visualizer. Once the Visualizer is deployed, Observer can access the Visualizer through a web-link using web-browser. With an intuitive navigation system, Observer is able to pick a desired content. The Visualizer retrieves needed data from the back-end, generates the content for display and returns it to Observer as response. If Observer visits the Visualizer while there is no running simulation, an empty layout page will be rendered.

Table 1: Use-case scenario – Observer observes the competition

Title:	Observer observes the simulation
Description:	Observer accesses the Visualizer using a web-browser, selects a content to display and observes the competition.
Primary actor:	Observer
Preconditions:	The Visualizer is deployed and the competition is running. Observer has a valid Internet connection.
Post conditions:	Observer's web-browser has a valid content displayed.
Main success scenario:	1. Observer enters the Visualizer through a web-link using web-browser. 2. Using navigation dock, Observer selects a page with a desired content. 3. Visualizer retrieves data, generates and returns the content. 4. Observer's web-browser renders an expected result.
Variations:	3a. No data to display. - Generate and return an empty layout page.

4.2.2. Use-case scenario (2): content view customization

This scenario (Table 2) follows the first use-case scenario (Table 1), after which Observer is already connected to the Visualizer and is able to observe the competition. Observer now might want to get a customized content view from the Visualizer. With the help of various widgets, Observer modifies the Visualizer to get a customized content view. Notable widgets include rich buttons and tabs. Rich buttons allow Observer hiding a specific layout unit and thus freeing more space for better user-experience. Tabs are extensively used in order to provide rich and intuitive content navigation. More details about the front-end design are given in the front-end module chapter.

Table 2: Use case scenario – Observer customizes the Visualizer using widgets

Title:	Observer customizes the Visualizer using widgets
Description:	Observer customizes the Visualizer to get a customized content view.
Primary actor:	Observer
Preconditions:	The Visualizer is deployed and the simulation is running. Observer is already observing the simulation.
Post conditions:	Observer successfully observes a customized content view from the Visualizer.
Main success scenario:	1. Using widgets, Observer modifies the Visualizer to get a customized content view. 2. The Visualizer processes Observer's modification. 3. The Visualizer retrieves, generates and returns a customized content view. 4. Observer’s web-browser renders a customized content.
Variations:	1a. Using rich buttons, Observer hides particular Visualizer layout units. 1b. Using checkboxes, Observer modifies the set of graphs to be displayed. 1c. Using tabs, Observer requests for a specific content (such as individual broker and customer model display) 1d. Using clickable wholesale table, Observer requests for a specific market view.

4.2.3. Use-case scenario (3): data analysis

In this scenario (Table 3), Competitor is interested in the exhaustive information about the running competition. The Visualizer provides the information about Competitor's broker, other brokers and competition environment. The information is contained within various graphs and data tables. This allows Competitor to get valuable input for the empirical research. Among other, Competitor can use the Visualizer to evaluate broker's strategies and reason about the market design.

Table 3: Use case scenario – Competitor analyses the game data

Title:	Competitor analyses the game data
Description:	By analysing the data, Competitor analyses his broker's performance and a competition environment (such as other brokers' behaviour, wholesale market interactions and customers' behaviour).
Primary actor:	Competitor
Preconditions:	The Visualizer is deployed and the simulation is running. Competitor is already observing the simulation.
Post conditions:	Competitor gets valuable input for the empirical research.
Main success scenario:	1. Competitor customizes the Visualizer to get a customized content. 2. Competitor proceeds with the analysis.
Variations:	2a. Competitor analyses his/her broker's performance. 2b. Competitor analyses a competition environment.

4.2.4. Use-case scenario (4): simulator set up

The Visualizer also has a competition management feature. It is used by Administrator to set up the simulator and run the competition (

Table 4). Prior to competition start, Administrator has to configure various simulation parameters (such as list of authorized brokers and competition configuration). With an appropriate button click, Administrator configures and starts the new competition. The Visualizer also provides exception handling, i.e. returns an error message for wrong competition parameter.

Table 4: Use case scenario – Administrator sets up the simulator

Title:	Administrator sets up the simulator
Description:	Prior to competition start, Administrator has to configure various simulation parameters.
Primary actor:	Administrator
Preconditions:	The Visualizer is deployed and the simulation is not running.
Post conditions:	Administrator successfully started the new competition.
Main success scenario:	1. Administrator navigates to competition control page. 2. Administrator enters a configuration file to be used. 3. Using pop-up dialog, Administrator specifies a list of authorized brokers for the simulation, displayed as a table. 4. Optionally, Administrator enters other parameters using appropriate forms. 5. Administrator clicks an appropriate button to start the competition. 6. Visualizer processes Observer's input and starts the competition.
Variations:	2a. Wrong game configuration filename entered. - The Visualizer returns an error message. 3a. Administrator specified a wrong list of authorized brokers. - Administrator edits a table of brokers.

4.2.5. Use-case scenario (5): message sending

This scenario describes an interaction between Simulator and the Visualizer (Table 5). Simulator is an actor that provides the competition. It is a simulation instance that communicates with the Visualizer by message sending. Upon new message receive, the Visualizer will call the appropriate message handlers and update its state. If the received message is of unknown type, the Visualizer will report a warning message to logger and resume to work.

Table 5: Use case scenario – Simulator sends a message to the Visualizer

Title:	Simulator sends a message to the Visualizer
Description:	Simulator runs the simulation and submits messages to the Visualizer. The main task for Visualizer is to update its state based on a received message.
Primary actor:	Administrator
Preconditions:	The Visualizer is deployed and registered for message listening. The simulation is running.
Post conditions:	The Visualizer successfully updated its state.
Main success scenario:	1. Simulator sends a message. 2. Visualizer receives a message. 3. Dispatches a message to appropriate message handlers. 4. Message handlers update the Visualizer’s state.
Variations:	3a. Unknown message type for a received message. - The Visualizer reports a warning message to logger.

4.3. Back-end module

The back-end module of the Visualizer is a module that contains the application logic for visualization of the Power TAC platform. Its main purpose is to communicate with both the simulator and the front-end module.

In order to communicate with the simulator, the front-end module implements a necessary infrastructure needed for registration with a proxy provided by the simulator. After the Visualizer has been successfully registered, the back-end module needs to receive a message from the simulator and update Visualizer’s state based on received message. To keep the complexity of communication within reasonable boundaries, the simulator does not require any input from the Visualizer except for registration process. Thus, communication with the simulator is achieved as a one-way message-based communication: the simulator is a message sender and the Visualizer is a message receiver. One of the main requirements for the Visualizer was to design for seamless integration with the Power TAC platform. This was the main guidance for choosing an appropriate technology for development of the back-end module. The back-end module is entirely developed using the Spring framework, the same technology used by all other Power TAC projects. This technology choice allows the avoidance of using additional technologies to glue the Visualizer and the simulator.

The back-end module will update Visualizer's state for each received message. Visualizer's state is represented by the most recent values of the Visualizer model objects. Information about customer's net usage of electricity is an example of such values. In order to allow front-end to build a representation of the Visualizer's state, the back-end module acts as a content repository for the front-end module. It is also responsible for configuring the simulator, based on an input from the front-end module that is used by the Administrator.

4.3.1. Back-end module architecture

The front-end module overview of the core architecture is given in Figure 12. Structure of the core architecture is separated into the following components:

- *competition management component*,
- *middleware component*,
- *message handling component*, and
- *model component*.

Each of these contains a distinct set of functionalities. Competition management component provides access to the simulator through use of the front-end user interface. Middleware component is responsible for registering Visualizer with the simulator and receiving messages. It also dispatches received messages to message handling component.

Components responsible for Visualizer's state update are message handling component and model component. Message handling component extracts the valuable information from received message and calls methods from model component in order to update Visualizer's state. Finally, model component is the set of domain objects that describe Visualizer's state.

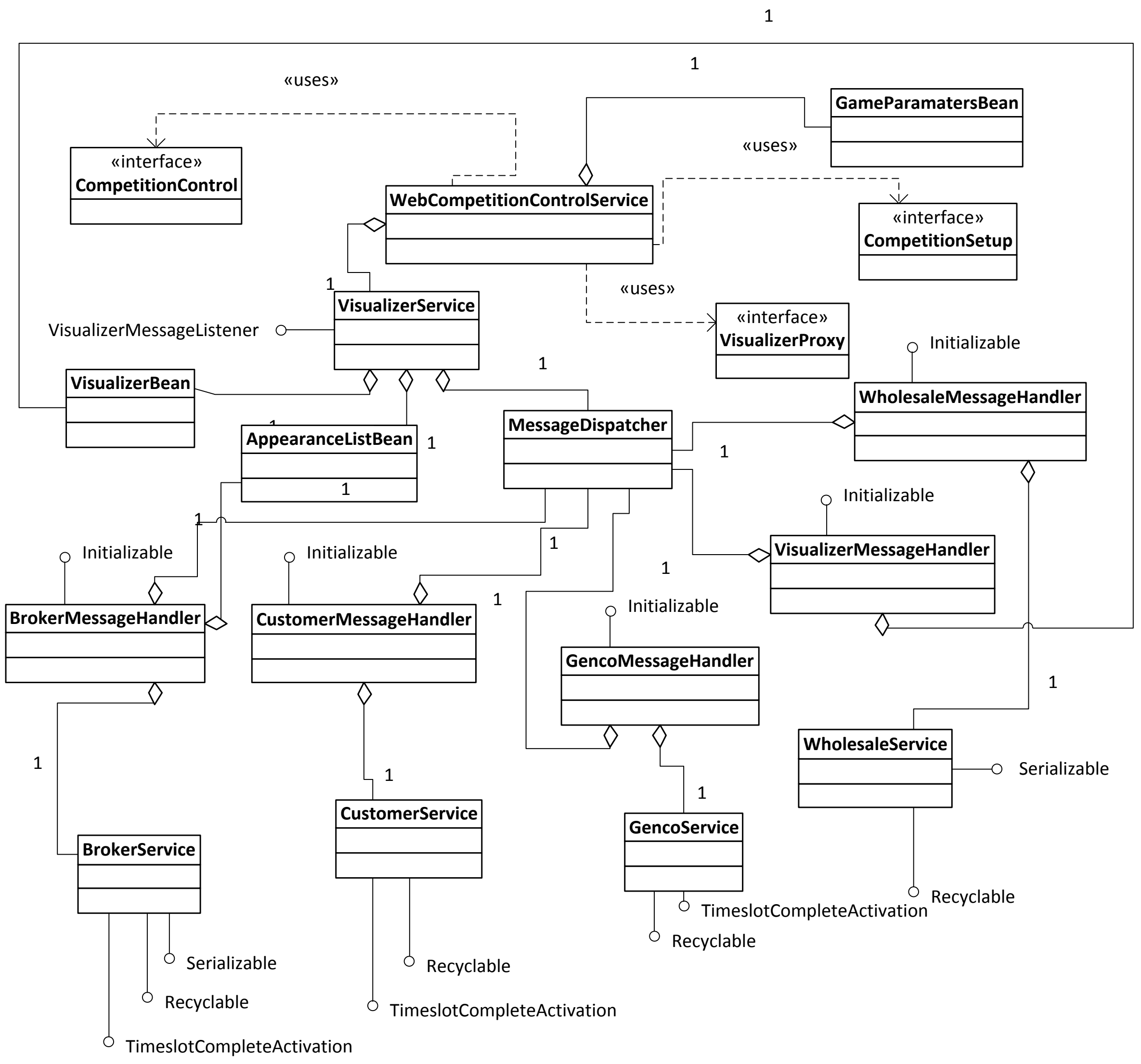


Figure 12: Class diagram - the core architecture overview

Competition management component

Competition management component provides access to the simulator through use of the front-end user interface. This component consists of the following main artefacts:

- `WebCompetitionControlService` is an object that provides methods for managing the simulator from the front-end module. Simulator management is possible through the use of `CompetitionControl` and `CompetitionSetup` interfaces. Prior to competition start, the

`WebCompetitionControlService` object will set up Middleware component with `VisualizerProxy` interface.

- `GameParametersBean` is an object used for storing competition configuration options. The list of brokers and the server configuration filename are some of possible configuration options held in `GameParametersBean` object.

Middleware component

Middleware component is responsible for registering Visualizer with the simulator and receiving messages. It also dispatches received messages to message handling component. This component consists of the following main artefacts:

- `VisualizerService` is an object that provides registration of the Visualizer by implementing `VisualizerMessageListener` interface. It is responsible for message receiving and calling `MessageDispatcher` object for message dispatching. It is used by competition management component to register the Visualizer back-end with the simulator. This will also trigger reset of the Visualizer’s state.
- `MessageDispatcher` is an object responsible for routing messages from `VisualizerService` object to message handling component.

Message handling component

Message handling component extracts the valuable information from received message and calls methods from model component in order to update Visualizer’s state. Each class within this component implements `Initializable` interface. By implementing this interface, objects from message handling component are able to register for an arbitrary set of message types. Registration is achieved by calling `MessageDispatcher` object’s method from middleware component. This component consists of the following main artefacts:

- `BrokerMessageHandler` is an object that registers for broker-related messages. Its primary goal is to extract valuable broker information from received message (i.e. cash position, tariff specification, tariff transaction, distribution transaction and balancing transaction) and update a broker model. At the competition start, `BrokerMessageHandler` object will assign an appearance for each broker using `AppearanceListBean` object.

- `CustomerMessageHandler` is an object that registers for customer-related messages. Its primary goal is to extract valuable information about a customer from received message (i.e. tariff transaction and customer's history usage) and update a customer's model.
- `GencoMessageHandler` is an object that registers for Genco-related messages. Its primary goal is to extract valuable information about the Genco from received message (i.e. cash position, market transaction and market position) and update a Genco model.
- `VisualizerMessageHandler` is an object that registers for competition-related messages. Its primary goal is to extract valuable competition information from received message (i.e. current timeslot, weather report and distribution report) and update a competition model.
- `WholesaleMessageHandler` is an object that registers for wholesale-related messages. Its primary goal is to extract valuable broker information from received message (i.e. order, order book and cleared trade) and update a wholesale market model.

Model component

Model component is the set of domain objects that describe Visualizer's state. These objects serve as a primary source of data for the front-end module's visualization process. Furthermore, objects from model component can be grouped in the following groups i.e. models:

- *Broker model* represents a group of objects that contain information about competing brokers. A simplified architecture overview of the broker model is given in Figure 13. `BrokerService` is an object that holds a collection of `BrokerModel` objects. The exact size of that collection depends on number of brokers participating in the competition. The `BrokerService` object acts as a mediator between `BrokerMessageHandler` object from message handling component and `BrokerModel` object. Such object will implement two interfaces: `TimeslotCompleteActivation` and `Recyclable`. The first interface allows the `BrokerService` to be called by message handling component after each timeslot has completed, while the second one indicates that the `BrokerService` object will be recycled, i.e. it will clear the list of brokers from the previous competition. The `BrokerModel` object represents a broker. Such object implements the following three interfaces: `VisualBroker`, `DisplayableBroker` and `TimeslotModelUpdate`. While the first two interfaces describe a list of methods needed for visualization purposes, the `TimeslotModelUpdate` interface indicates that the `BrokerModel` object will be updated after the end of each timeslot. Broker's portfolio records are kept within multiple `CustomerModel` objects, one for each customer model in the competition. Broker's graph data can be found in the `BrokersJSON` object, while broker's aggregate day results are kept in the `DayState` object.

- *Competition model* contains objects for recording general information about the competition, including: current timeslot, current day, current week, weather report. It also contains an animation model for the day overview.
- *Customer model* contains objects for recording information about customers, including: cash outflow, cash inflow, produced energy, consumed energy and historical net usage data.
- *Genco model* contains objects for recording information about generation companies or Gencos. Since the Gencos only participate in the wholesale market, the Genco model will record Genco's wholesale market performance and financial performance.
- *Wholesale model* contains objects for recording information about wholesale market interactions. This include a list of available markets, list of market clearings for a particular market, list of bids and asks before the market clearing, list of bids and asks after the market clearing and information about total traded quantities.

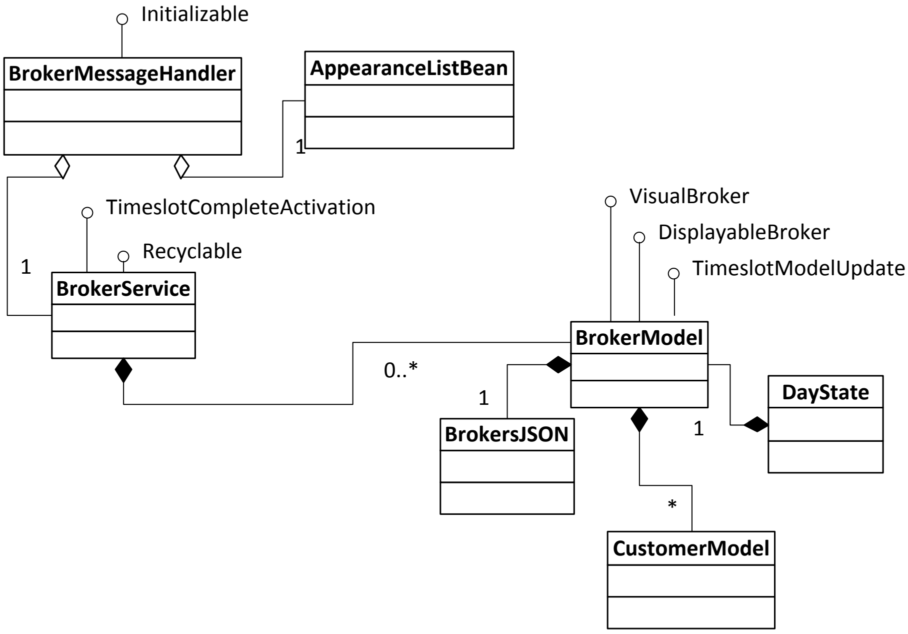


Figure 13: Class diagram – architecture overview of the broker model

4.3.2. Visualizer’s state update mechanism

Visualizer’s state is determined by current values from the model component. It is used by the front-end module to retrieve the needed data and generate visualization in form of a web-page. One of the main characteristics of Visualizer’s state is that it directly reflects the real-time status of the competition. In order to support the real-time data representation, it is very important to develop an efficient mechanism for Visualizer’s state update.

Such mechanism should be able to quickly handle a message received from the simulator and update the Visualizer’s state. Since the back-end module receives a large number of messages, the per-message state update might not be a reasonable option: creating new immutable objects after each message is received can have a significant negative impact on the Visualizer’s performance and can lead to a lower-quality service. An additional reason for not utilizing a per-message state update is the user perspective: the end-user is generally not interested in an instant state update. Instead, the user is more likely to require a complete competition overview with a reasonable update period. This assumption has led to the solution for the Visualizer’s state update mechanism, shown in Figure 14. A specific message type (`TimeslotComplete`) is used to trigger Visualizer’s state updating. This message is typically received every five seconds from the simulator, although the interval can vary depending on the competition setup.

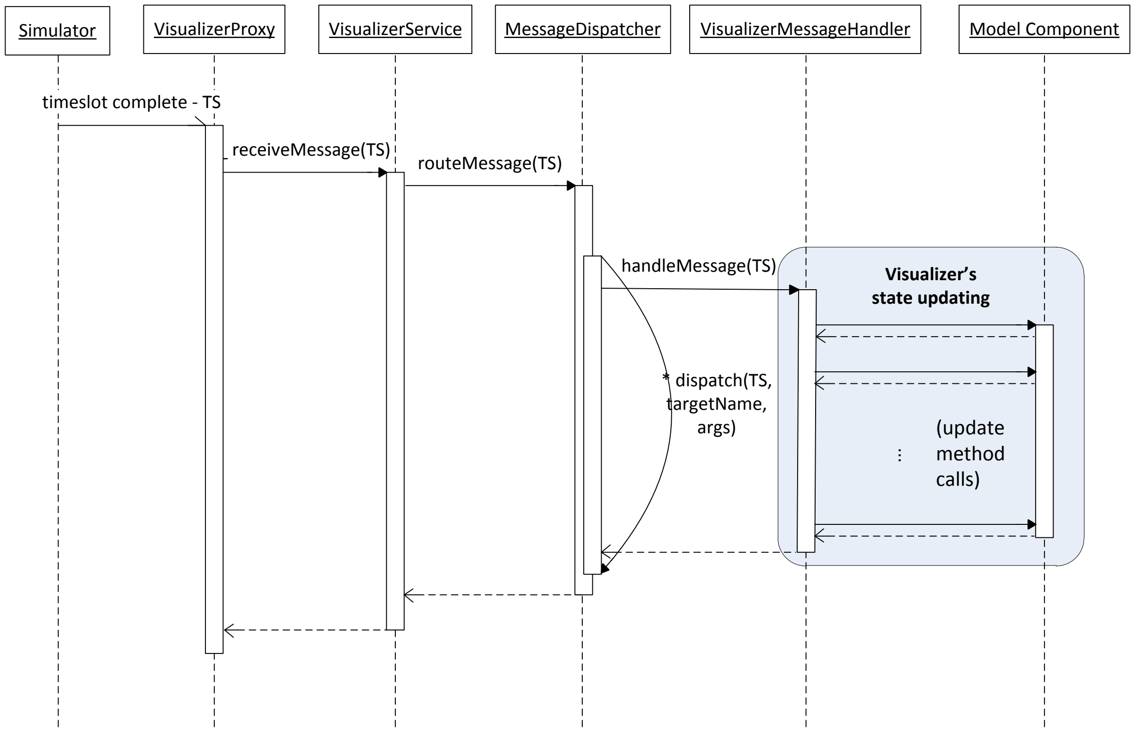


Figure 14: Sequence diagram – shows message handling and Visualizer's state updating

First, the simulator sends the `TimeslotComplete` message to `VizualizerProxy` object. `VizualizerProxy` object forwards the message to `VisualizerService` with a `receiveMessage(TS)` method call after which `VisualizerService` calls the `MessageDispatcher`'s `routeMessage(TS)` method. `MessageDispatcher` will now iterate over handler objects that were registered for a `TimeslotComplete` message. In an example from Figure 14, such handler object is `VisualizerMessageHandler`. The final step in this mechanism is an actual update of the Visualizer's state using update method calls for objects from the model component.

This procedure helps to maintain a sufficiently good user experience in terms of the updated display of information, while maintaining performance requirements within satisfactory boundaries.

4.4. Front-end module

The front-end module of the Visualizer is a module that contains the presentation logic for visualization of the Power TAC platform. Its main purpose is to retrieve necessary data from the back-end module and use that data to create rich and intuitive representation of the Power TAC competition. In addition to rich visualization, the front end module also provides an administration interface for competition management. The Visualizer competition control replaces the manual set up of the simulator that uses the command line interface.

The front-end module was developed using JSF-related and standard Web technologies. Software artefacts from this module are web pages. The basic skeleton of a page is built using *Facelet* template facility, provided by JSF. Implementation of the master layout provided consistent look for all the web pages. To provide rich visual design, the *Primefaces* library was used. One of the widgets from the *Primefaces* that were used for page navigation is the dock element. In order to support the analysis of the competition, various charts that describe the work of individual Power TAC entities were implemented. Visualizer's charts are provided by *jqPlot* library and they include line charts, pie charts and bubble charts. Dynamic display of content was achieved using a periodic page update mechanism.

To meet the need for a high-level overview, an animation in the *Game overview* page was implemented. The game overview page does not provide a detailed insight into the competition data; instead, it is able to demonstrate the basic interactions between entities in the competition.

Pages that show the competition content are based around the Power TAC entities. Entities that have separate pages are:

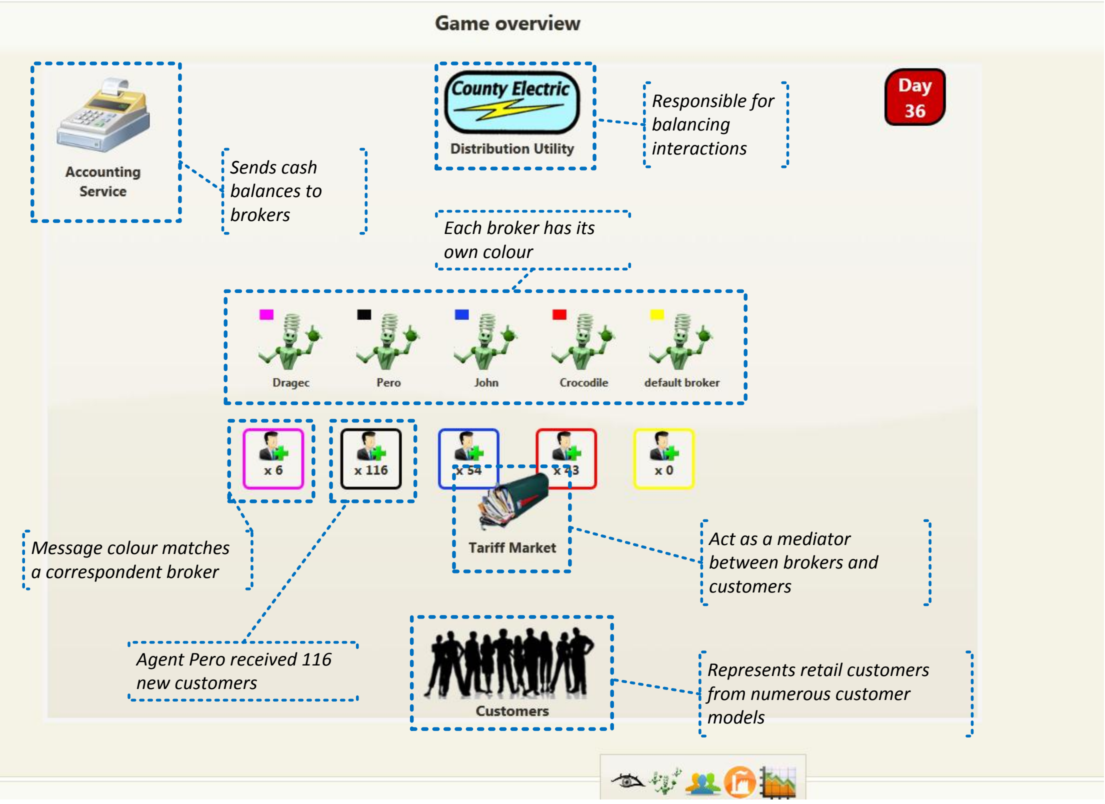
- brokers,
- customers,
- generation companies, and
- wholesale market.

In order to support the ability to administer the competition over the Visualizer, the *Competition control* page was developed.

More details about each of these developed pages are presented in the following chapters.

4.4.1. Game overview

The Power TAC simulation design is composed of numerous entities that mutually interact. This makes the competition quite complex. This can be an obstacle for people who are not within the Power TAC community and can ultimately cause the low-level of popularity of the platform. To tackle these issues, the Visualizer provides a high-level game overview for casual users. Such overview does not have a detailed insight into the competition data; instead, it is able to demonstrate the basic interactions between entities in the competition. To create a high-level game overview, the front-end module needs to retrieve a reduced set of information available from the back-end module and create the appropriate visualization. The solution for the game overview is implemented in the form of animation. Designing of animation was done using XHTML and CSS, while the actual simulation movements were achieved with the help of JavaScript and jQuery library. Game overview is provided in the *Game Overview* page (Figure 15) of the Visualizer.



Sends cash balances to brokers

Responsible for balancing interactions

Each broker has its own colour

Message colour matches a correspondent broker

Act as a mediator between brokers and customers

Agent Pero received 116 new customers

Represents retail customers from numerous customer models

Figure 15: Game overview is represented with animation

Brokers who are currently competing in the game are set in the middle. Each broker is represented with one colour. The colour links the broker with broker's interactions. An example of interaction is a moveable message that contains information about number of new customer that subscribed to broker. This message travels from *Customers* over the *Tariff market*, to the *receiving* broker. Animation currently supports the following visualization of per-day information:

- number of new customers that subscribed to broker,
- number of customers that withdrew from broker,
- number of new tariffs sent by broker,
- balancing fee from distribution utility to broker, and
- broker's financial status.

The main problem for the game overview visualization is the game speed: typical competition configuration specifies a duration timeslot of five seconds. Within a timeslot, competitive brokers interact with numerous entities, such as tariff market, customers and distribution utility. It is obvious that it takes more than five seconds to efficiently display just the important interactions from a timeslot. To counteract this problem, a day view model is built within the back-end module. This model aggregates the timeslot data to a day data. The front-end module uses the day view model to prepare the animation. A sequential display of the activities for building an animation can be seen in Figure 16. First, the front-end module contacts the back-end module to retrieve the day overview data. Once the front-end receives the day overview data, it is necessary to dynamically generate needed XHTML elements. The front-end will create XTML elements for entities and interactions among them. Interactions between entities are shown as moveable messages. An example of a moveable message is the information about balancing report: it travels from the distribution utility to the receiving broker. Once the elements are generated, it is necessary to generate an animation scenario. Generation of scenarios involves determining the trajectory for each moveable element. The last step before launching animation is to set timeout for each movable element, in order to have a desired sequence of movements.

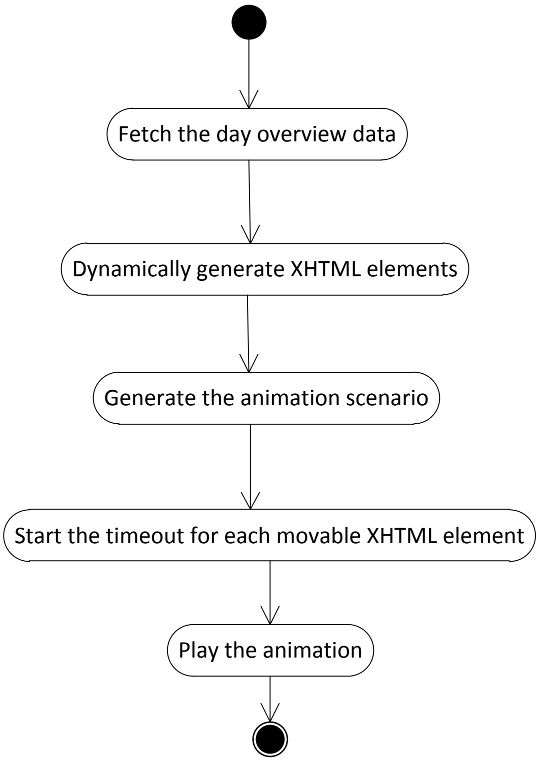


Figure 16: Activity diagram – the game overview animation

4.4.2. Brokers

Broker, represented by a trading agent, is the main element of the Power TAC competition scenario. In each timeslot, a broker goes through a three-step process: trading in the wholesale market, portfolio management and balancing. More details about this process can be found in chapter 2.2.1.

A trading agent that competes in the Power TAC competition is developed by a research team. Before they submit broker to a final competition, research teams goes through iterative process that includes coding and evaluation of a broker. For evaluation part, research teams are allowed to use the generated logs for finding useful information. While logs can provide a detailed insight into the competition's message flow, they are highly inconvenient for a frequent use.

To help research teams with the evaluation process, the Visualizer front-end module provides an extensive representation of brokers with *Brokers* page (Figure 17). Using tab widget, user is able to pick an individual broker to display. User is also able to watch both the individual info and aggregate info from all the brokers at the same time. Aggregate info is placed on the right side of the page, next to the main content, and it is part of a master page layout. This allows users to have the crucial information about brokers on every other page. The following elements are shown in the aggregate info (Figure 18):

- *data table* showing current rankings of competing brokers,
- *line chart* showing cash balance time series for every broker, and
- *pie chart* showing current market share for competing brokers.

Data table shows relative positions of competing brokers. Each broker is represented by a row with the following info:

- *an icon,*
- *cash position,*
- *energy balance,* and
- *number of broker's customers*.

Line chart shows cash positions of each broker for all timeslots. It is useful for studying financial behaviour of brokers.

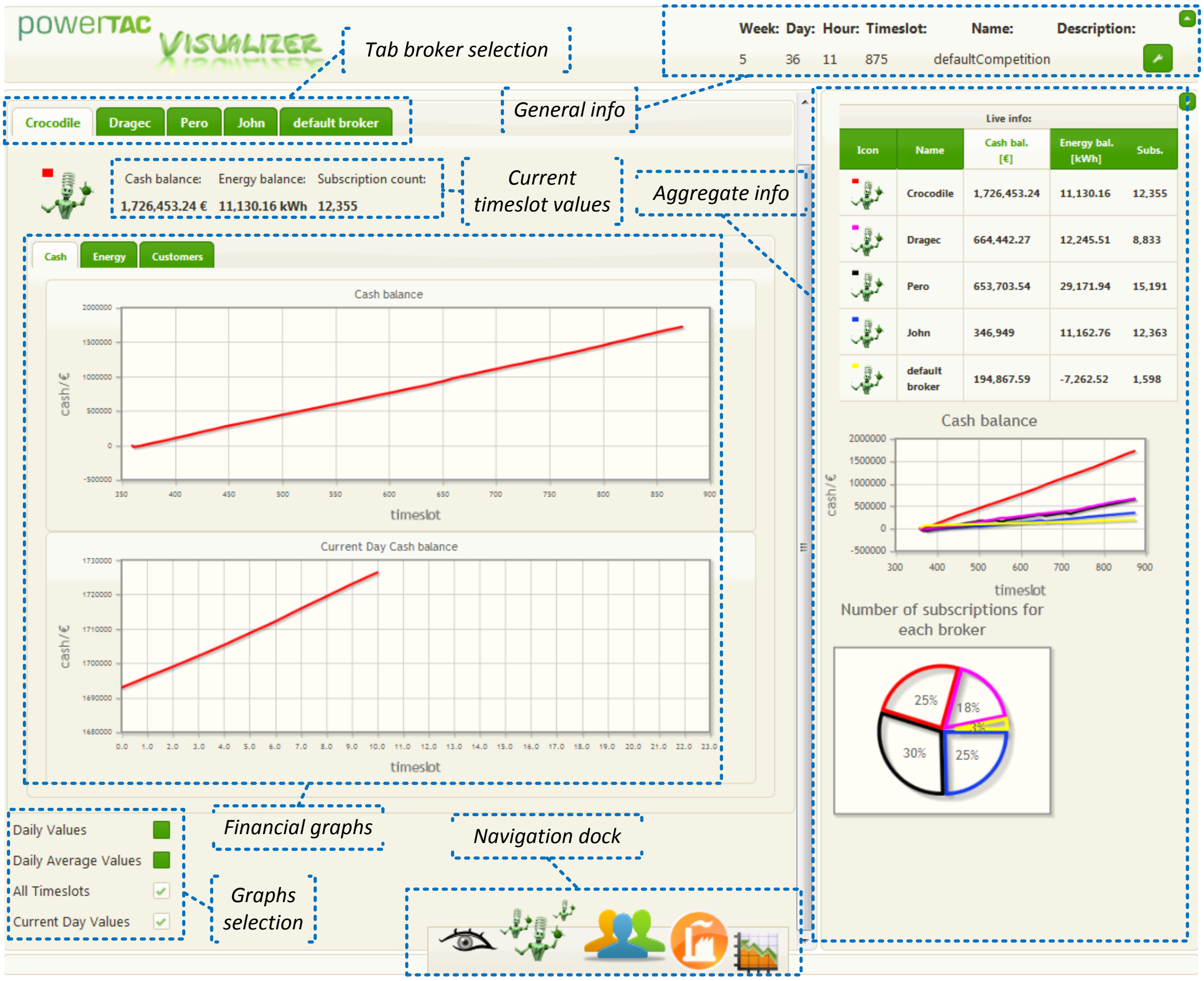
Pie chart displays market shares of each broker. Market share is determined by broker's number of customers.

Individual info contains information about broker's current cash balance, energy balance and subscription count. Beneath this, user can choose the content from the following three sections: finance section, energy balance section and portfolio section.

Finance section

Design of the finance section is shown in Figure 17. For a selected broker, the front-end Visualizer module will display line charts that show broker's evolution of finance status. User can use checkbox widgets to select an arbitrary set of charts, including:

- *daily values chart,*
- *all values chart values,* or
- *current day values chart.*



Week:	Day:	Hour:	Timeslot:	Name:	Description:
5	36	11	875	defaultCompetition	

Cash balance:	Energy balance:	Subscription count:
1,726,453.24 €	11,130.16 kWh	12,355

Live info:

Icon	Name	Cash bal. [€]	Energy bal. [kWh]	Subs.
🟥	Crocodile	1,726,453.24	11,130.16	12,355
🟪	Dragec	664,442.27	12,245.51	8,833
⬛	Pero	653,703.54	29,171.94	15,191
🟦	John	346,949	11,162.76	12,363
🟨	default broker	194,867.59	-7,262.52	1,598

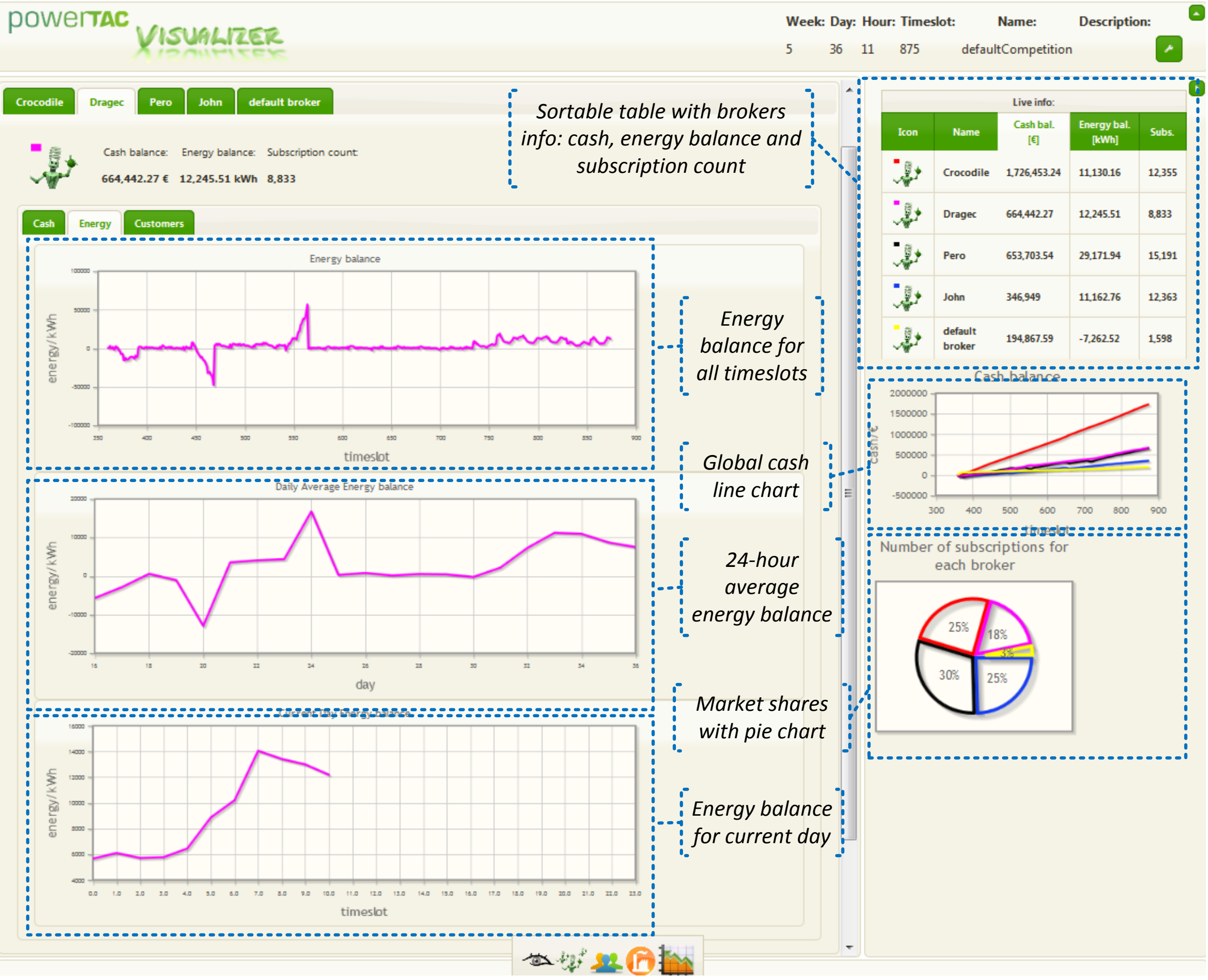
Daily Values 🟩
Daily Average Values 🟩
All Timeslots ☑
Current Day Values ☑

Figure 17: Broker’s financial status

Energy balance section

Design of the energy balance section is shown in Figure 18. It has the similar look as the finance section. For a selected broker, the front-end Visualizer module will display line charts the shows broker’s energy balance. Since the broker’s promising strategy is to keep energy imbalance as low as possible, this section can provide useful insights about how an individual broker handles the balancing process. User can customize the view to get an arbitrary set of charts, including:

- *all timeslots values chart*,
- *current day values chart*, and
- *daily average values*.



Week:	Day:	Hour:	Timeslot:	Name:	Description:
5	36	11	875	defaultCompetition	

Cash balance:	Energy balance:	Subscription count:
664,442.27 €	12,245.51 kWh	8,833

Live info:

Icon	Name	Cash bal. [€]	Energy bal. [kWh]	Subs.
🟥	Crocodile	1,726,453.24	11,130.16	12,355
🟪	Dragec	664,442.27	12,245.51	8,833
⬛	Pero	653,703.54	29,171.94	15,191
🟦	John	346,949	11,162.76	12,363
🟨	default broker	194,867.59	-7,262.52	1,598

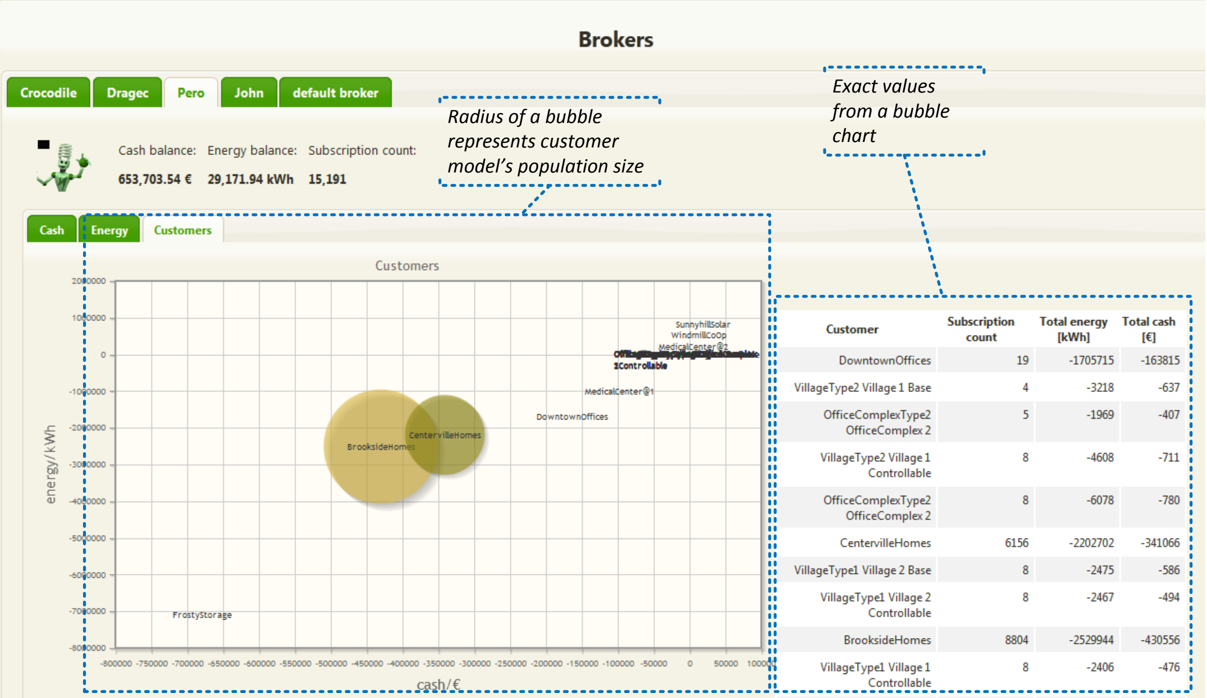
Figure 18: Broker’s energy balance

Portfolio section

Design of the portfolio section is shown in Figure 19. Broker’s portfolio is represented by both bubble chart and data table. Each entry in a bubble chart denotes one customer model that represents a population subscribed to an observed broker. It displays the current status in three dimensions:

- *total cash* (x-axis),
- *total energy* (y-axis), and
- *population size* (radius).

Total cash is the total cash balance for a particular customer model. Negative values implies that broker earned money on customer model, while positive values implies that broker lost money on customer model. Thus, customers that are towards left side of the chart are more profitable than ones on the right. Similar observation goes for a total energy, which is a total energy produced (positive values) or consumed (negative values) by a particular customer model. The producers are placed in the upper part of the chart, above the zero. Since consumers have negative values, they will be placed in the bottom part of the chart, under the zero. Users can also use the data table to review the actual numbers represented by a bubble chart.



Radius of a bubble represents customer model's population size

Exact values from a bubble chart

Cash balance:	Energy balance:	Subscription count:
653,703.54 €	29,171.94 kWh	15,191

Customer	Subscription count	Total energy [kWh]	Total cash [€]
DowntownOffices	19	-1705715	-163815
VillageType2 Village 1 Base	4	-3218	-637
OfficeComplexType2 OfficeComplex 2	5	-1969	-407
VillageType2 Village 1 Controllable	8	-4608	-711
OfficeComplexType2 OfficeComplex 2	8	-6078	-780
CentervilleHomes	6156	-2202702	-341066
VillageType1 Village 2 Base	8	-2475	-586
VillageType1 Village 2 Controllable	8	-2467	-494
BrooksideHomes	8804	-2529944	-430556
VillageType1 Village 1 Controllable	8	-2406	-476

Figure 19: Broker's portfolio

4.4.3. Customers

Retail customers are essential entities connected to the grid. They can be producers, consumers or prosumers. In the real life, such customers can be households, office complexes, small wind turbines, electric vehicles or similar. In Power TAC, these customer types are modelled into customers models. Each customer model has different behaviour, including different consumption pattern, the way customer model evaluates tariff and responses to a dynamic price change.

To address the need for representation of customer models, the *Customers* page was developed. Navigation between customer models is enabled through the use of tab widgets. Each customer model has info about:

- *population size*,
- *number of active subscriptions*, and
- *power types*.

List of power types is visualized in form of icons. The Visualizer front-end visualizes three generic power types with icons. Generic power types are:

- *production type* (*positive thunderbolt icon*, shown in Figure 21),
- *consumption type* (*negative thunderbolt icon*, shown in Figure 20) and
- *storage type* (*battery icon*).

Beneath this info, user can select the content from the following sections:

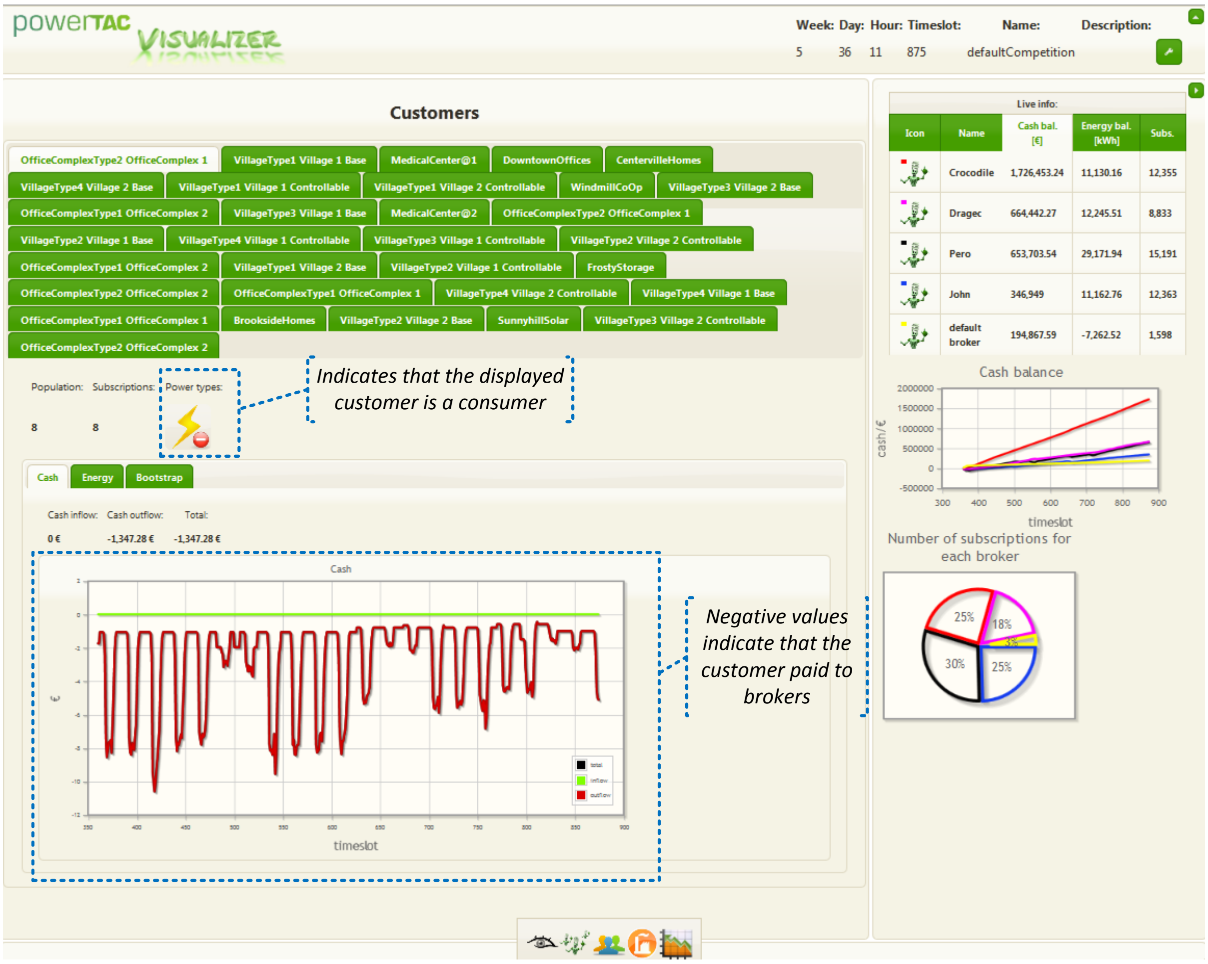
- *finance section*,
- *energy section*, and
- *historical consumption data section*.

Finance section

Design of the customer's finance section is shown in Figure 20. For a selected customer model, the front-end Visualizer module will display a current timeslot values and line chart that shows customer model's evolution of finance status. Line chart consists of three series:

- *outflow series*,
- *inflow series*, and
- *total series*.

Outflow series shows the amount of money a particular customer model paid from all brokers. On the contrary, inflow series shows the amount of money a particular model received from all brokers. An aggregate finance situation of a customer model is given with total series.



Week: 5 Day: 36 Hour: 11 Timeslot: 875 Name: defaultCompetition Description:

Population: 8
Subscriptions: 8
Power types:

Cash inflow: 0 €
Cash outflow: -1,347.28 €
Total: -1,347.28 €

Live info:

Icon	Name	Cash bal. [€]	Energy bal. [kWh]	Subs.
🟥	Crocodile	1,726,453.24	11,130.16	12,355
🟪	Dragec	664,442.27	12,245.51	8,833
⬛	Pero	653,703.54	29,171.94	15,191
🟦	John	346,949	11,162.76	12,363
🟨	default broker	194,867.59	-7,262.52	1,598

Indicates that the displayed customer is a consumer

Negative values indicate that the customer paid to brokers

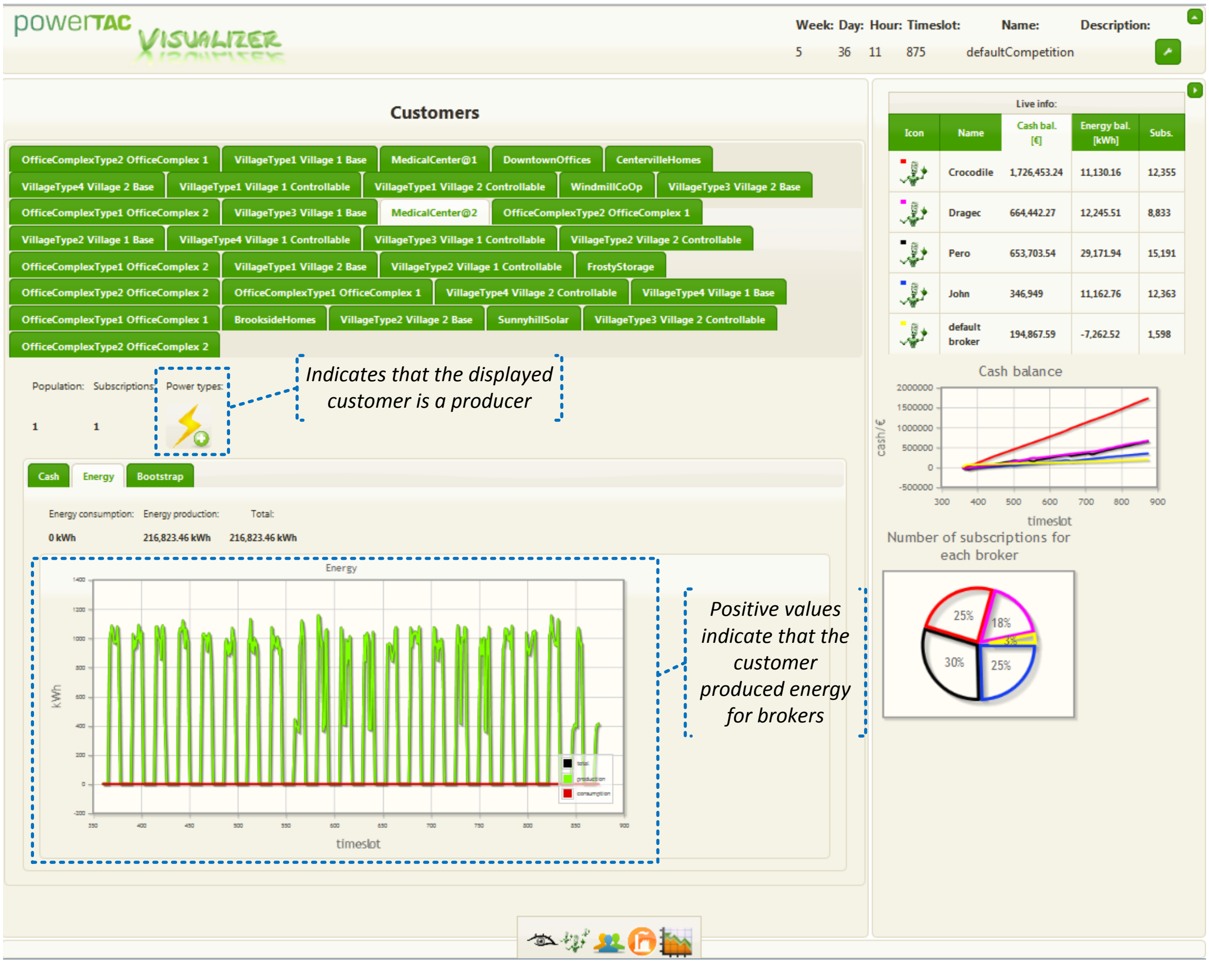
Figure 20: Customer’s financial status

Energy section

Design of the customer’s finance section is shown in Figure 21. For a selected customer model, the front-end Visualizer module will display a current timeslot values and line chart that shows customer model’s evolution of energy usage. Line chart consists of three series:

- *production series*,
- *consumption series*, and
- *total series*.

Production series shows the amount of energy a particular customer model produced for all brokers. On the contrary, consumption series shows the amount of energy a particular model consumed from all brokers. An aggregate energy situation of a customer model is given with total series.



Week: 5
Day: 36
Hour: 11
Timeslot: 875
Name: defaultCompetition
Description:

Population: 1
Subscriptions: 1
Power types:

Energy consumption: 0 kWh
Energy production: 216,823.46 kWh
Total: 216,823.46 kWh

Live info:

Icon	Name	Cash bal. [€]	Energy bal. [kWh]	Subs.
🟥	Crocodile	1,726,453.24	11,130.16	12,355
🟪	Dragec	664,442.27	12,245.51	8,833
⬛	Pero	653,703.54	29,171.94	15,191
🟦	John	346,949	11,162.76	12,363
🟨	default broker	194,867.59	-7,262.52	1,598

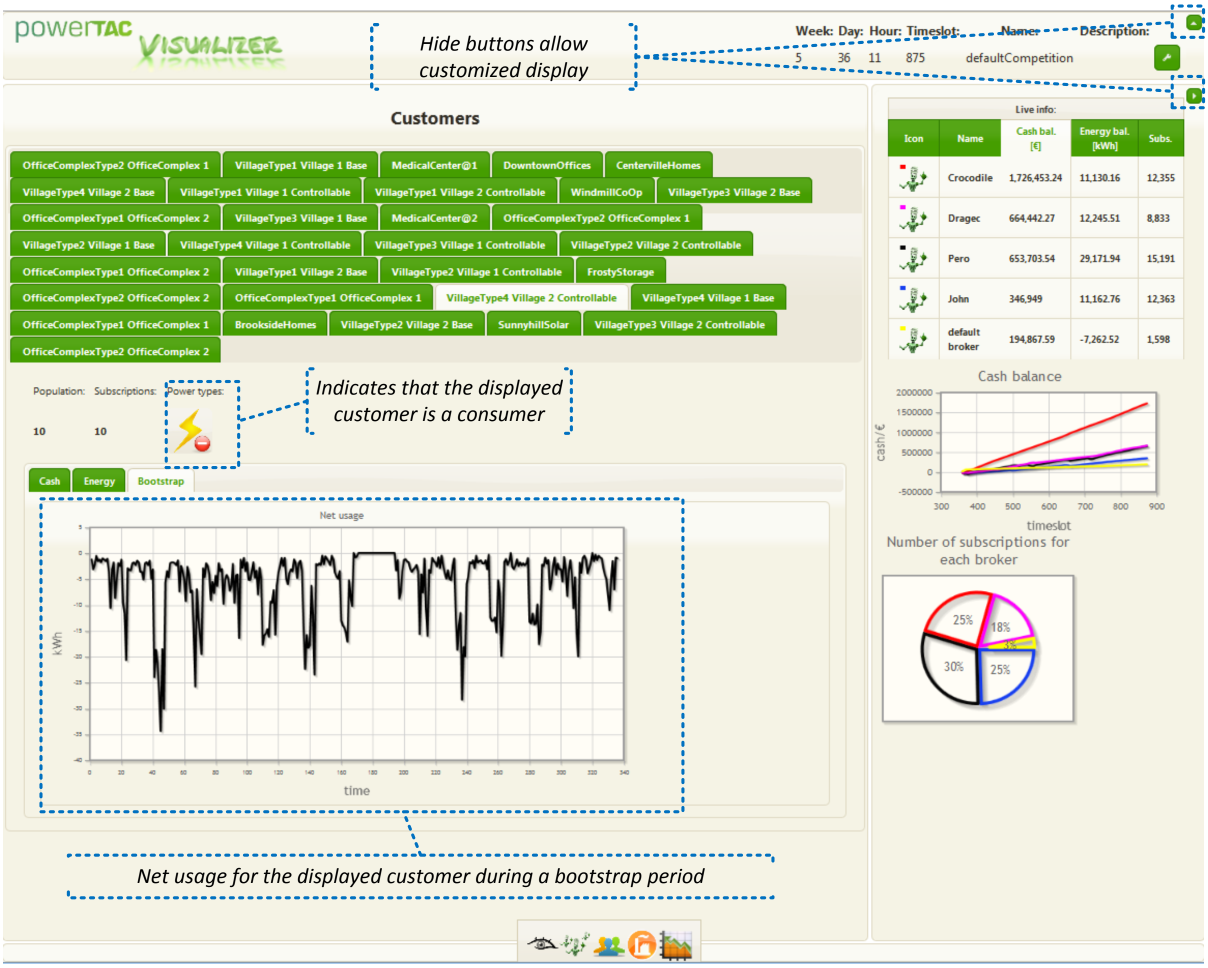
Indicates that the displayed customer is a producer

Positive values indicate that the customer produced energy for brokers

Figure 21: Customer's energy

Historical consumption data section

Design of the customer's historical consumption data section is shown in Figure 22. For a selected customer model, the front-end Visualizer module will display a line chart that shows consumption and production data for each customer model for the 14 days preceding the start of the simulation, under the terms of the default tariffs provided by the distribution utility.



Hide buttons allow customized display

Indicates that the displayed customer is a consumer

Net usage for the displayed customer during a bootstrap period

Live info:

Icon	Name	Cash bal. [€]	Energy bal. [kWh]	Subs.
🟥	Crocodile	1,726,453.24	11,130.16	12,355
🟪	Dragec	664,442.27	12,245.51	8,833
⬛	Pero	653,703.54	29,171.94	15,191
🟦	John	346,949	11,162.76	12,363
🟨	default broker	194,867.59	-7,262.52	1,598

Figure 22: Customer's consumption pattern from a bootstrap period

4.4.4. Generation companies

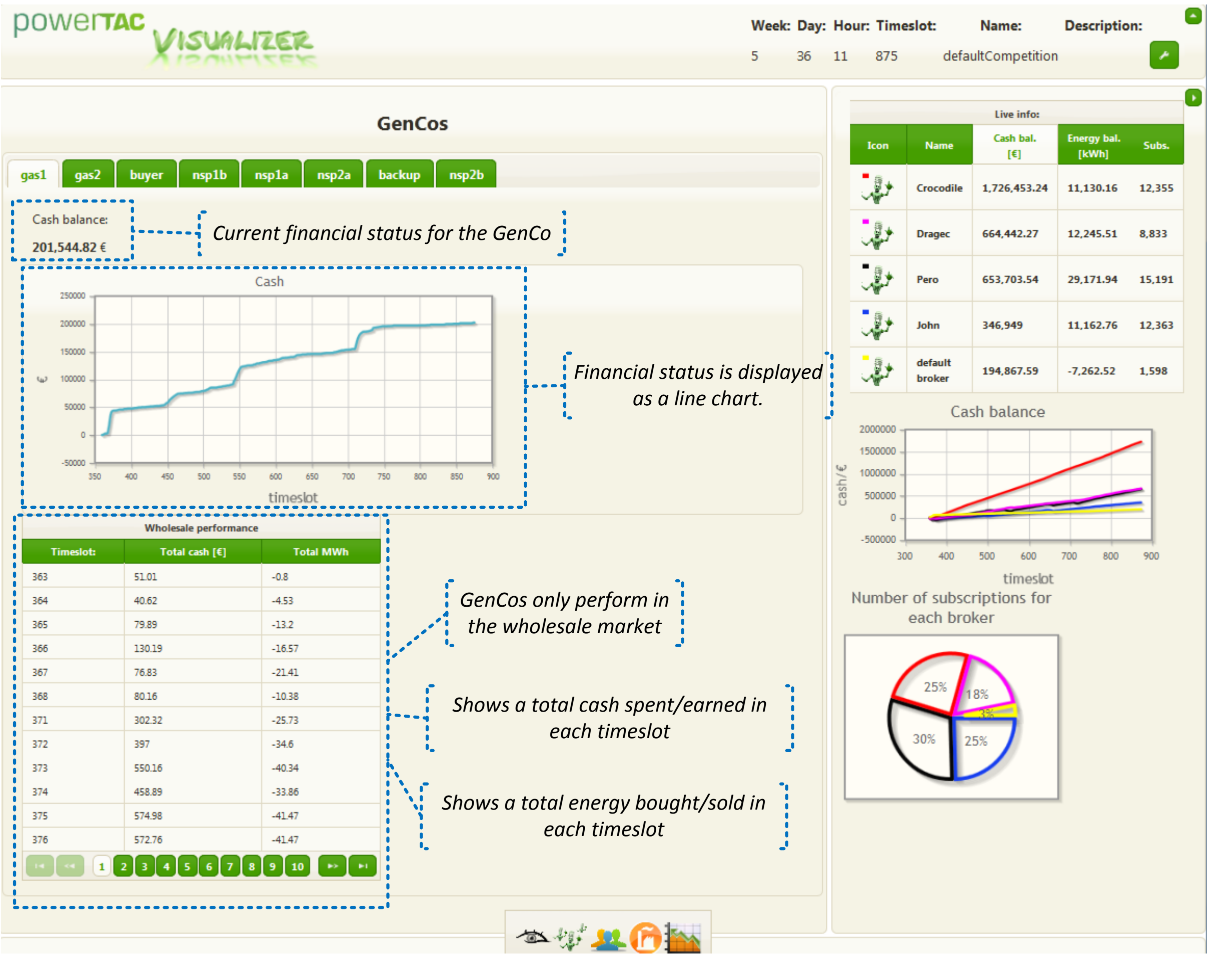
The generation companies, or simply Gencos, are entities that only participate in the wholesale market. A large industry plant from smart-grid deployment (Figure 3) is the real-life example of such entity. To provide users possibility to get an overview of Gencos' effect on the competition, the *Gencos* page (Figure 23) was developed.

Navigation between Gencos is enabled with the use of tab-widget. The content for each Genco consists of:

- *current financial status*,
- *financial line chart*, and
- *wholesale performance data table*.

The wholesale performance data table provides a display of aggregate results in trading for a particular Genco. Each row of the data table is defined by:

- *timeslot for which trades were made*,
- *total financial balance*, and
- *total energy traded*.



Week: 5
Day: 36
Hour: 11
Timeslot: 875
Name: defaultCompetition
Description:

Cash balance: 201,544.82 €

Current financial status for the GenCo

Financial status is displayed as a line chart.

Live info:				
Icon	Name	Cash bal. [€]	Energy bal. [kWh]	Subs.
🟥	Crocodile	1,726,453.24	11,130.16	12,355
	Dragec	664,442.27	12,245.51	8,833
⬛	Pero	653,703.54	29,171.94	15,191
🟦	John	346,949	11,162.76	12,363
🟨	default broker	194,867.59	-7,262.52	1,598

Wholesale performance		
Timeslot:	Total cash [€]	Total MWh
363	51.01	-0.8
364	40.62	-4.53
365	79.89	-13.2
366	130.19	-16.57
367	76.83	-21.41
368	80.16	-10.38
371	302.32	-25.73
372	397	-34.6
373	550.16	-40.34
374	458.89	-33.86
375	574.98	-41.47
376	572.76	-41.47

1 2 3 4 5 6 7 8 9 10

GenCos only perform in the wholesale market

Shows a total cash spent/earned in each timeslot

Shows a total energy bought/sold in each timeslot

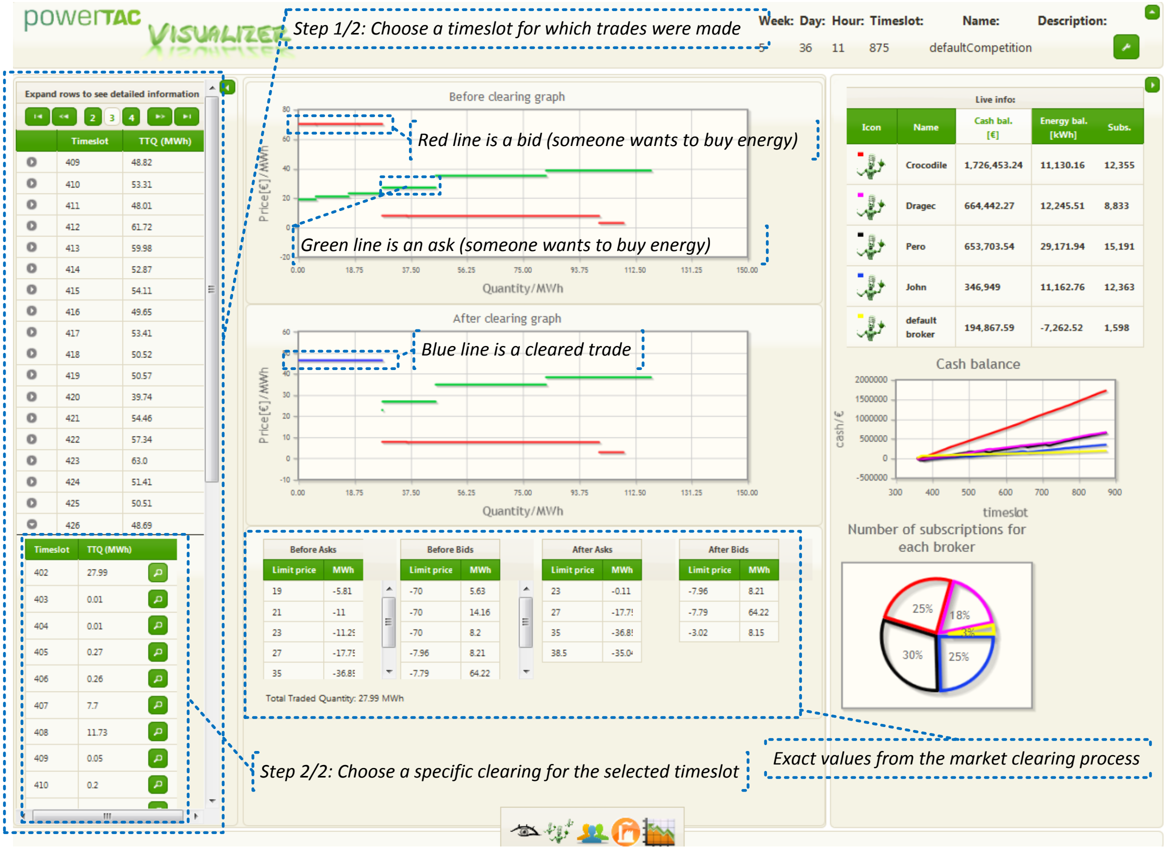
Figure 23: Financial status and wholesale performance for generation companies

4.4.5. Wholesale market

The wholesale market is used by brokers and Gencos to buy and sell quantities of energy for future delivery, up to 24 timeslots in the future. In Power TAC, this market works as a periodic double auction, clearing once every timeslot.

To address the need for wholesale market visualization, the *Wholesale* page was developed (Figure 24). It provides an overview of a market clearing. The navigation between market clearings is provided with clickable tables on left side of the page. Since there can be multiple clearings for each timeslot, the two-table system were used. First table lists all the delivery timeslots, including a total traded quantity for that timeslot. Each row can expand with an inner table that contains all the clearings for a delivery timeslot specified in the outer table. Clearing process is visualized with two line charts:

- *before clearing graph*, and
- *after clearing graph*.



Step 1/2: Choose a timeslot for which trades were made

Red line is a bid (someone wants to buy energy)

Green line is an ask (someone wants to buy energy)

Blue line is a cleared trade

Step 2/2: Choose a specific clearing for the selected timeslot

Exact values from the market clearing process

	Timeslot	TTQ (MWh)
○	409	48.82
○	410	53.31
○	411	48.01
○	412	61.72
○	413	59.98
○	414	52.87
○	415	54.11
○	416	49.65
○	417	53.41
○	418	50.52
○	419	50.57
○	420	39.74
○	421	54.46
○	422	57.34
○	423	63.0
○	424	51.41
○	425	50.51
○	426	48.69

Timeslot	TTQ (MWh)
402	27.99
403	0.01
404	0.01
405	0.27
406	0.26
407	7.7
408	11.73
409	0.05
410	0.2

Before Asks

Limit price	MWh
19	-5.81
21	-11
23	-11.2
27	-17.7
35	-36.8

Before Bids

Limit price	MWh
-70	5.63
-70	14.16
-70	8.2
-7.96	8.21
-7.79	64.22

After Asks

Limit price	MWh
23	-0.11
27	-17.7
35	-36.8
38.5	-35.0

After Bids

Limit price	MWh
-7.96	8.21
-7.79	64.22
-3.02	8.15

Total Traded Quantity: 27.99 MWh

Live info:

Icon	Name	Cash bal. [€]	Energy bal. [kWh]	Subs.
🟥	Crocodile	1,726,453.24	11,130.16	12,355
🟪	Dragec	664,442.27	12,245.51	8,833
⬛	Pero	653,703.54	29,171.94	15,191
🟦	John	346,949	11,162.76	12,363
🟨	default broker	194,867.59	-7,262.52	1,598

Figure 24: Wholesale market

The *before clearing graph* contains all the bids and asks gathered for a specific timeslot clearing. The result of the clearing is displayed with *after clearing graph*. Each order, visualized by a horizontal line, is represented by energy quantity and price. Red line visualizes a bid order, green line visualizes an ask order and black line visualizes a market order. If there was a cleared trade in a particular market clearing, an appropriate message will be displayed at the bottom. Both graphs have associated tables with the exact values from the market clearing process.

4.4.6. Competition control

In addition to rich visualization, the front-end module also provides an administration interface for competition control. This allows an easy configuration of the simulator according to user preferences. The Visualizer competition control replaces the manual set up of the simulator that uses the command line interface.

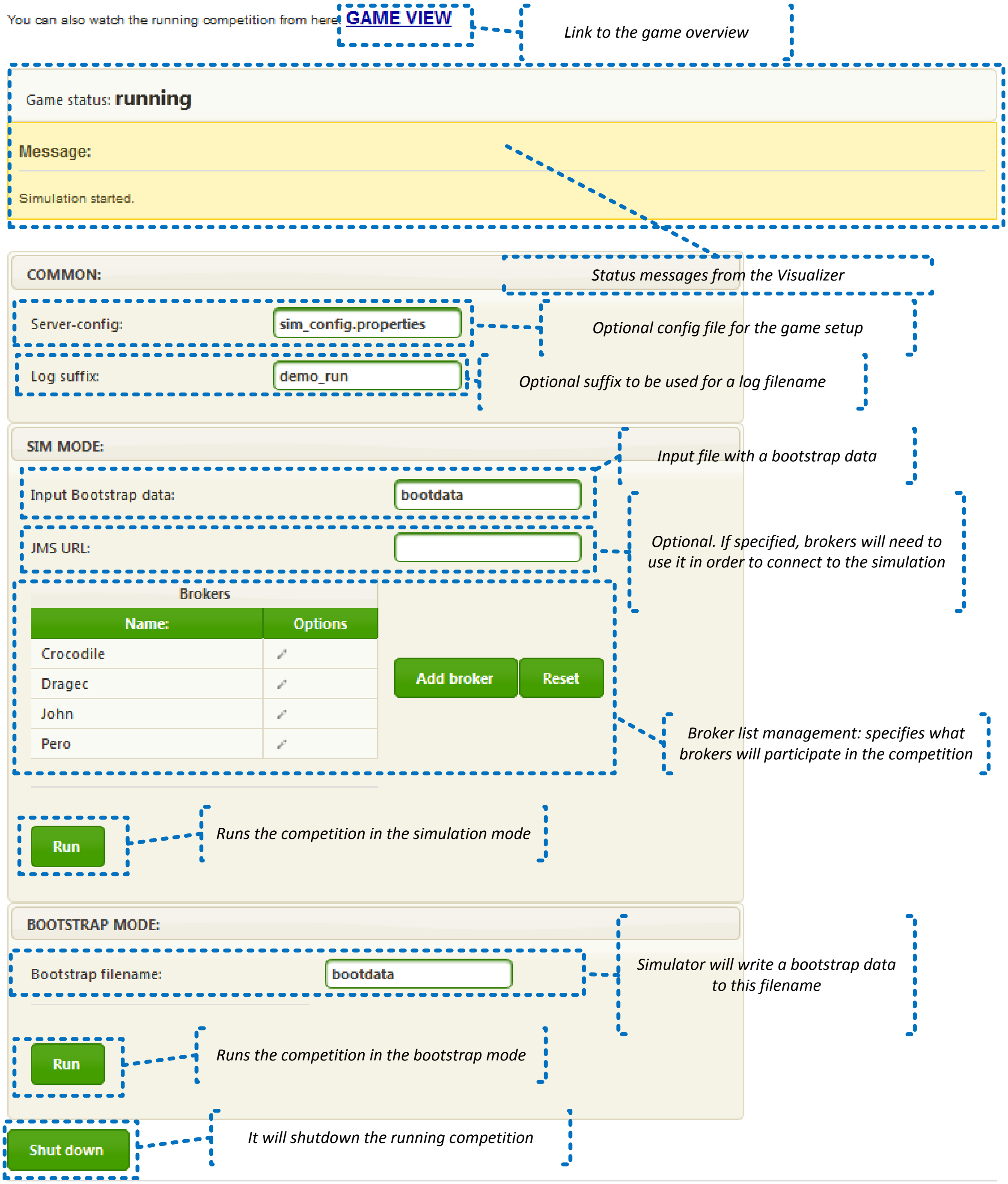
Design of the *Competition control* page is shown in Figure 25. At the top there is a link to the visualization part of the front-end module. Below the link, there is a space for displaying status messages. Depending on the inputs received from the user, the Visualizer displays the message about the success of the user action and the status of the game. In Figure 25, the front-end module reports that the game has successfully started and is in running status. The game configuration parameters are entered using text-input forms and data table. It is possible to configure and run two game modes:

- *bootstrap mode*, and
- *sim mode*.

The *bootstrap mode* is a game mode that runs without competing brokers. It is used to generate data that serves as input for the sim mode. To configure this mode it is necessary to enter a filename for the output file that will contain the result of the bootstrap mode game.

The *sim mode* is a game mode that runs an actual simulation with competing brokers. This mode has the following parameters:

- *input bootstrap data*,
- *jms url*, and
- *list of authorized brokers*.



You can also watch the running competition from here GAME VIEW

Game status: **running**

Message:

Simulation started.

COMMON:

Server-config: sim_config.properties

Log suffix: demo_run

SIM MODE:

Input Bootstrap data: bootdata

JMS URL:

Name:	Options
Crocodile	✎
Dragec	✎
John	✎
Pero	✎

BOOTSTRAP MODE:

Bootstrap filename: bootdata

Link to the game overview

Status messages from the Visualizer

Optional config file for the game setup

Optional suffix to be used for a log filename

Input file with a bootstrap data

Optional. If specified, brokers will need to use it in order to connect to the simulation

Broker list management: specifies what brokers will participate in the competition

Runs the competition in the simulation mode

Simulator will write a bootstrap data to this filename

Runs the competition in the bootstrap mode

It will shutdown the running competition

Figure 25: Admin interface – competition control

Input bootstrap data requires the name of the file that was generated in the bootstrap mode. *Jms url* is an optional parameter that will override standard URL of the message broker used by brokers. *List of authorized brokers* is the list of brokers that will participate in the game. Broker names are specified using data table.

Both modes use two common optional configuration options:

- *server-config*, and
- *log suffix*.

Server-config file has properties that override the standard server configuration. Log suffix option gives the root name for the log files. Once the required parameters are set, the game can be started with the *Run* button.

4.4.7. Periodic partial page update mechanism

One of the features front-end module has is a dynamic visualization. This allows automated update of the page content, including tables and graphs. Dynamic visualization is achieved with the period partial page update mechanism that takes use of AJAX technology. It updates only the relevant parts of a page to minimize the unnecessary network traffic load.

The sequential diagram that shows the mechanism is given in Figure 26. After the initial page load, the observer interacts with the Visualizer front-end module. The interaction lasts for five seconds, after which the front-end module issues a periodic AJAX request to the back-end module. The first task for the back-end module is to analyse parameters from a received request. When the first task is finished, the back-end module will be aware of the content it needs to provide for the front-end module. The back-end module fetches the needed data from component model, prepares an AJAX response and sends it to the front-end module. The final step in this mechanism is for the front-end module to do a partial update. This includes destroying the previous content to create space for the new data. Finally, after the front-end module cleaned the previous content, it will fill appropriate components with the new data from an AJAX response. User will now have an automatically updated page without the use of complete page refresh. This sequence is repeated in loop to provide an up-to-date visual data representation.

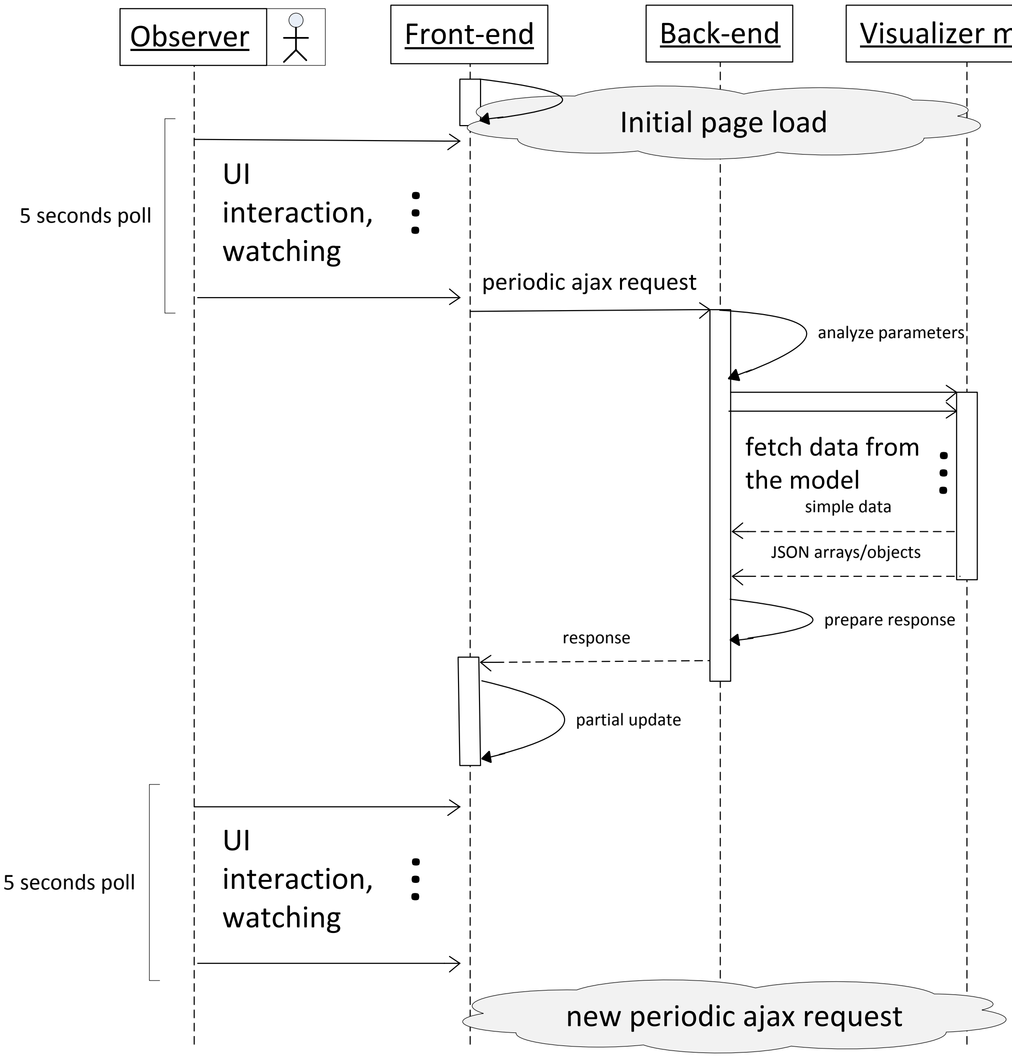


Figure 26: Sequence diagram – shows the partial page update

Conclusion

Electric power systems of the future (usually referenced as smart grids) will be based on digitally enabled electrical grid that will gather and distribute electrical power based on behaviour of all stakeholders (suppliers and consumers) in order to improve the efficiency, reliability, economics and sustainability of electricity services. However, such systems will need more than low-cost renewable energy sources – they will also need efficient price signals that motivate sustainable energy consumption as well as a better real-time alignment of energy demand and supply.

The Power Trading Agent Competition (TAC) is an agent-based simulation platform designed to enable exploration of the retail electricity market. The main goal of the Power TAC is to give a complete overview of the possibilities and limitations of open markets to identify good practices and policy guidelines necessary for management of smart grids. The Power TAC platform offers a great deal of flexibility by enabling to incorporate many different types of consumer or producer models, as well as simulate different scenarios.

The Power TAC is developed in the cooperation of six universities across Europe and North America, including the University of Zagreb. Responsibility of the University of Zagreb’s team is to develop a visualization module for the Power TAC platform. The Power TAC Visualizer is a crucial component for the success of the whole Power TAC project because not only it enables real-time observing of Power TAC competitions, but also provides enhanced analysis of stakeholders’ behaviour in the Power TAC market and as such presents a grounding for identifying good practices for smart grid management.

In early June 2012, at the International Joint Conference of Autonomous Agents and Multi-Agent Systems (AAMAS 2012) in Valencia, the Power TAC competition will run for the first time. Around 20 international teams from industry and academia will pit their agents against one another. Afterwards, they will share results so that stakeholders from academia, industry and government can learn from the process and identify good practices and policy guidelines necessary for management of smart grids.

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Sažetak

Postojeći elektroenergetski sustavi se transformiraju iz tradicionalnih energetskih mreža u napredne energetske mreže (engl. *smart grids*). Promjene koje se događaju u elektroenergetskom sektoru utjecat će na način kojim potrošači koriste električnu energiju. Zahvaljujući novim tehnološkim rješenjima, korisnik postaje važan element u stvarno-vremenskom uravnoteženju ponude i potražnje za energijom unutar lokalnog područja. Uz tehničku dimenziju naprednih energetskih mreža, od presudne je važnosti uspostaviti maloprodajno tržište električnom energijom koje će podržati tržišne procese unutar sustava naprednih energetskih mreža. Posljedično, ono što nedostaje povrh tehničke infrastrukture jest efikasan skup tržišnih mehanizama. S ciljem izbjegavanja loše oblikovanog tržišta, a prije nego što napredne energetske mreže dosegnu globalnu rasprostranjenost, potrebno je osigurati bez-rizično okružje za testiranje tržišnih regulativa.

Natjecanje Power TAC (engl. *Power Trading Agent Competition*) modelira tržište električne energije, a osmišljeno je kao otvorena tržišna simulacijska platforma čiji cilj je definirati smjernice za dizajn tržišta električne energije na temelju rezultata robusnog istraživanja o strukturi i radu takvog tržišta. Projekt Power TAC je međunarodni projekt koji se provodi u suradnji šest sveučilišta iz Europe i Sjeverne Amerike, uključujući i Sveučilište u Zagrebu. Odgovornost tima koji predstavlja Sveučilište u Zagrebu jest razvoj vizualizacijskog modula za platformu Power TAC. Razvijeno rješenje, predstavljeno u ovom radu, nije samo skalabilno i robusno programsko rješenje zasnovano na najsuvremenijim tehnologijama, već ima veliku znanstvenu vrijednost budući da predlaže rješenje za razumijevanje dinamike tržišta električne energije kroz identifikaciju, analizu i prezentaciju dionika, procesa i ključnih interakcija u okružju naprednih energetskih mreža.

Početkom lipnja 2012. godine, natjecanje Power TAC po prvi puta će se održati za vrijeme konferencije *International Joint Conference of Autonomous Agents and Multi-Agent Systems* (AAMAS 2012) u Valenciji. Otprilike 20 međunarodnih timova iz industrije i akademske zajednice suprotstavit će svoje agente jedan protiv drugog. Nakon toga će razmijeniti rezultate kako bi dionici iz akademske zajednice, industrije i državne uprave mogli identificirati dobre prakse i smjernice za regulativu koja omogućuje efikasno upravljanje naprednim energetskim mrežama. Power TAC Visualizer, odgovornost zagrebačkog tima unutar projekta Power TAC, presudna je komponenta za uspjeh cjelokupnog projekta jer ne samo da omogućuje stvarno-vremensko praćenje natjecanja Power TAC, već dodatno omogućuje naprednu analizu ponašanja dionika na tržištu Power TAC te kao takva predstavlja temelj za identificiranje dobrih praksi za upravljanje naprednim energetskim mrežama.

Ključne riječi: napredne energetske mreže, simulacijska platforma, programski agenti, vizualizacija tržišta električne energije, Power Trading Agent Competition

Summary

The current electrical power systems are switching from a traditional grid to an advanced grid called smart grid. Changes that occur in the electricity sector will affect the way customers use electricity. Thanks to new technological solutions, a user becomes an essential element in real-time alignment of energy demand and supply within the local area. In addition to technical aspects of smart grid, establishment of the retail electric energy market for supporting the market aspect of the smart grid systems is crucial. Consequently, what is lacking in addition to technical infrastructure of a smart grid is an efficient set of market mechanisms. In order to avoid bad market design once smart grids are going to be widely deployed, it is necessary to provide a risk-free environment for testing market regulative.

Power Trading Agent Competition (Power TAC) is an open, competitive market simulation platform that addresses the need for policy guidance based on robust research result on the structure and operation of retail electrical energy markets. The Power TAC is an international project created with the cooperation of six universities across Europe and North America, including the University of Zagreb. Responsibility of the University of Zagreb's team is to develop a visualization module for the Power TAC platform. Developed solution, presented in this paper, is not only scalable, robust and based on state-of-the-art technologies, but has a huge scientific value because it proposes a solution to seize dynamics of electric power markets through identifying, analysing and presenting stakeholders, processes and key interactions in a smart grid environment.

In early June 2012, at the International Joint Conference of Autonomous Agents and Multi-Agent Systems (AAMAS 2012) in Valencia, the Power TAC competition will run for the first time. Around 20 international teams from industry and academia will pit their agents against one another. Afterwards, they will share results so that stakeholders from academia, industry and government can learn from the process and identify good practices and policy guidelines necessary for management of smart grids. The Power TAC Visualizer, Zagreb's team responsibility within the Power TAC project, is a crucial component for the success of the whole project because not only it enables real-time observing of Power TAC competitions, but also provides enhanced analysis of stakeholders' behaviour in the Power TAC market and as such presents a grounding for identifying good practices for smart grid management.

Keywords: smart grids, simulation platform, software agents, electricity trading visualization, Power Trading Agent Competition

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