Conceptual design and architecture of an informatics solution for smart trading on wholesale energy market in Romania

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This paper presents conceptual design and architecture of an informatics solution that aims to implement analytical models for optimization and forecasting the electricity demand and generation, simulation and what if analysis for efficient trading activities on wholesale energy markets in Romania. The informatics solution will be developed as a prototype on a cloud computing platform in order to allow easy access to energy providers and network operators.

Keywords: *energy forecasting, balancing, optimization, cloud computing, energy market*

1 Introduction

This paper presents some preliminary studies regarding the research project "Intelligent system for trading on wholesale electricity market" (SMARTRADE) which is supported by National Authority for Scientific Research and Innovation through European Regional Development Fund (ERDF). Objective of the project is to design and develop an informatics prototype for forecasting, analysis and decision models for energy providers, in order to estimate energy demand and generation in a suitable way for an efficient trading on the wholesale energy market.

A prototype will be developed on a private cloud computing architecture and will be addressed to electricity providers and network operators alike, especially to the Transmission System Operator (TSO) and the Distribution System Operators (DSO), for estimation of the electricity demand and generation at the national/regional level. An important component of the informatics prototype consists in a forecast module that accurately predict the electricity generation/demand on short and medium term for all interested market participants (providers/producers) constituted as balance responsible parties (BRP). Main scope is to establish efficient trading offers on the energy market, based on business rules and decision models. This scope will be reached by going through the following specific objectives:

- Building a data model for processing information collected from smart metering systems, but also from trading markets;
- Establishing a consumption prediction component within BRP, taking into account the behavior of producers-consumers (prosumers);
- Establishing a component for the prediction of energy generation from renewable sources at BRP level which can improve predictions for hourly intervals and daily averages so that the costs related to imbalances can be reduced;
- Establishing an optimization component for electricity generation and consumption of BRP;
- Establishing business rules and decision models related to trades on energy markets;
- Developing interfaces for access to prediction, optimization, analysis and simulation services for energy providers and TSOs/DSOs alike.

Components will be developed and implemented into an informatics prototype for simulation and decision support at the level of providers/producers constituted as BRP. Also, the informatics prototype will offer decisional support at the level of network operators by integrating data coming from providers and analyzing it in order to efficiently plan national/regional resources. The project's objectives are important in the context of not only the current need to integrate a higher volume of energy produced from renewable energy sources (RES), but also the need to implement smart metering systems to consumers until 2020, according to [1] and [2].

2 Conceptual design

First stage of the project is the conceptual design including; resources, methodologies and technologies that can be defined and used in the project. Conceptual design of the prototype is made based on following main objective; to develop a software platform which will be utilized to ensure supply and demand balance along a planning period in an electricity market. Supply and demand balance should satisfy transmission network constraints in an optimum manner. Optimality is due to fact that supply and demand balance could be satisfied by several solutions in a constrained network. Redispatching the generators based on merit order, cutting of generation from renewables when they are generating quite high amount of energy, and load shedding are among those solutions to ensure supply demand balance while satisfying network constraints [3]-[5]. Whether the solution is optimum or not in terms of cost effectiveness is the main question, which is intended to be answered by means of the proposed optimization techniques in the software platform.

Balancing problem has two main aspects: demand forecast and corresponding supply solution taking into account network constraints. Demand forecast is among the main inputs to the balancing problem. The software proposed in this study focuses on short-term supply demand balance problem. Short term corresponds to day ahead. Demand forecast should be performed for 24 hours along a day under the assumption that the settling interval of the electricity market is one hour, as in the case of Romania and most EU countries [6].

Electricity demand forecast is a probabilistic problem in nature [7]. Given this probabilistic aspect, the longer forecasting period, the larger error gap as illustrated in Fig. 1.

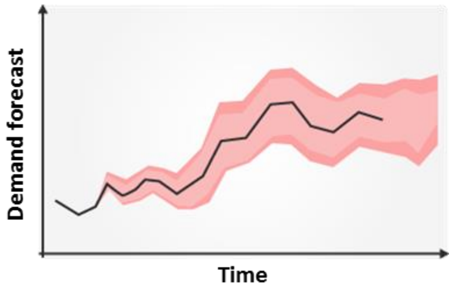

Fig. 1. Probabilistic load forecast

Literature includes both deterministic and probabilistic short-term electricity demand projection approaches. Deterministic approaches which define normal, high and low demand scenarios are also commonly utilized in supply demand balancing problems [8]. In this study, a probabilistic demand forecast module is designed. Upper and lower levels of the probabilistic demand forecast are assumed to be high and low demand forecast scenarios, respectively. Average is assumed to be normal scenario. These normal/low/high demand forecast scenarios are utilized deterministically in the simulations.

Short-term demand forecast analysis are proposed to be performed under a dedicated forecasting module of the software platform. Renewable generation forecasting module is the other forecasting module of the platform as depicted in Fig. 2. Renewable generation sources are classified as; wind, PV and run-of-river hydros. Renewable generation forecasting problem is also probabilistic in nature.

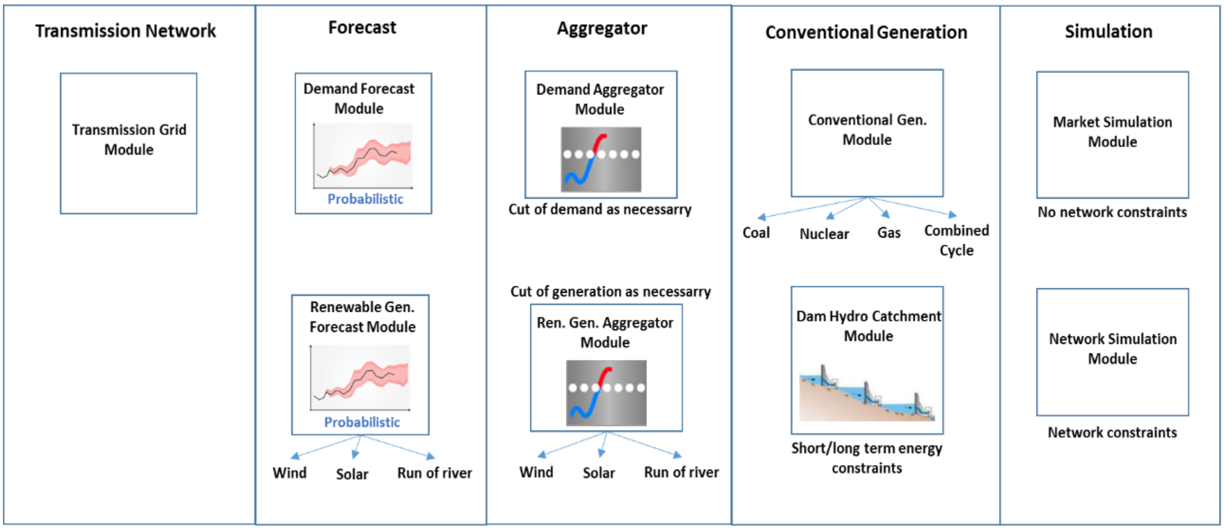

Fig. 2. Modules of the prototype

Renewable generations will be considered as negative loads in the software platform, like in many studies relevant in the literature [9]. It is assumed that generation from renewables are injected to the network directly. It is essential that demand forecast minus renewable generation forecast will give net demand of the system. This net demand should be supplied by conventional generators which mainly includes; nuclear, gas, coal, fuel, and dam-type hydro. In addition to that, these conventional generators should provide spinning reserves for balancing the supply and demand minute by minute. The software platform proposed in this study determines optimum commitment and dispatch of the conventional generators in order to balance supply and net demand while ensuring network constraints and reserve requirements. Commitment of cascaded hydro power plants is a challenging problem which should consider dependencies of the power generation of the power plants located on the same river [10]. Therefore, a dedicated module is designed for hydro catchment problem as shown in Fig. 3.

Cut of generation from renewable sources and load shedding will be considered as flexibility options to ensure supply and demand in the short-term, as illustrated in Fig. 3. Since it is a short-term supply demand balancing problem, such flexibility options might be indispensable particularly in case of supply deficiency and/or transmission constraints. Such issues can essentially be resolved by proper generator and/or transmission investments in the long-term. Nevertheless, the proposed platform, which focuses on short term supply demand balancing problem, can be utilized for identifying necessary investments in the long-term as well.

Aggregator modules will be considered in modeling either demand or renewable generation shedding. Demand and renewable generation aggregator modules are representing demand shedding capability and renewable generation shedding capability for the balancing problem, respectively.

Supply and demand balance problem is proposed to be solved by ignoring network constraints first. This step is called as “market simulation” which gives supply and demand balance result assuming that all the generation and loads are connected to the same bus. Then, “network simulation”, which takes the results of the market simulation as input, is run. Network constraints are relaxed by the following options depending their cost effectiveness: i) changing commitments and/or redispatching of the conventional generators, ii) load and/or renewable generation shedding. Input/output interrelation of the modules and sequential market and network simulation approach are illustrated in Fig. 3.

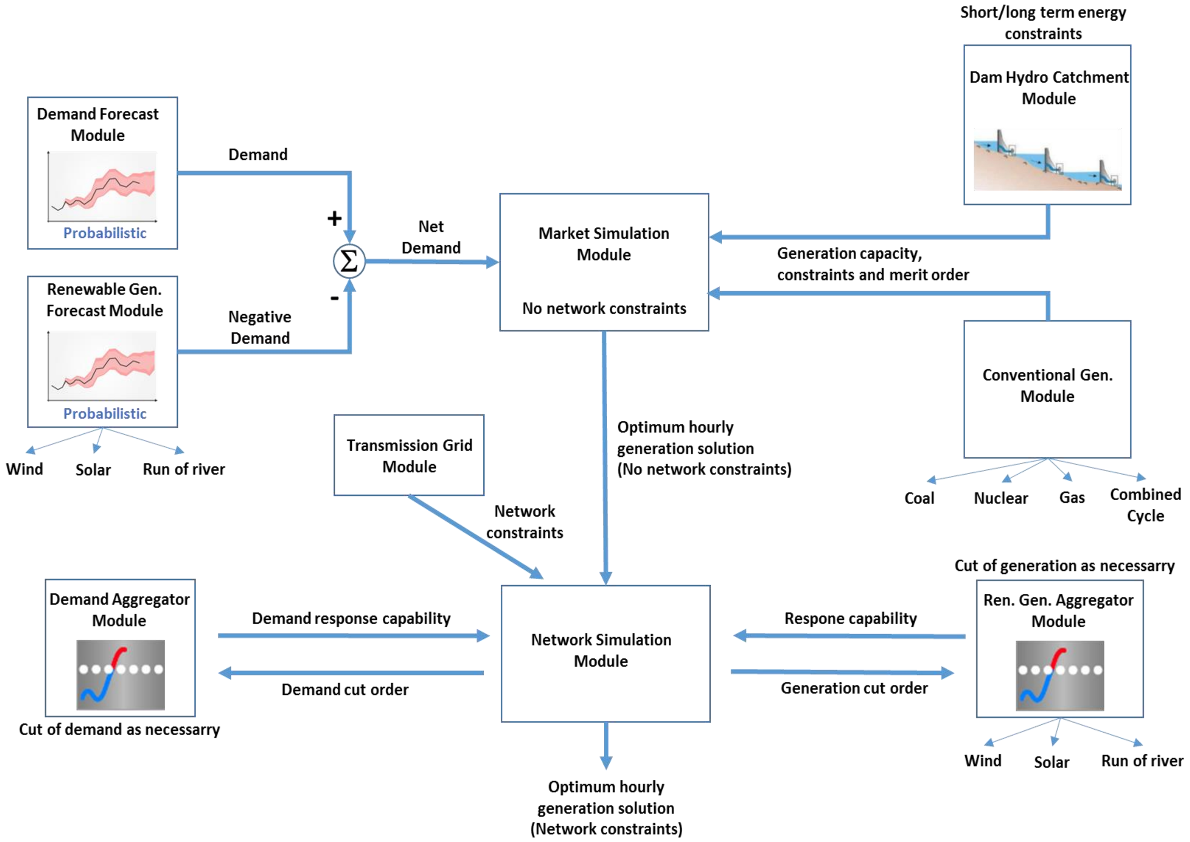

Fig. 3. Conceptual design of the proposed solution

3 Proposed architecture

The prototype will be created in an online environment on a cloud computing infrastructure which will offer providers the required infrastructure to process and analyze data, without being required to invest in their own hardware and software equipment. A simulation and analysis component service will be instanced and configured in the cloud computing environment for each energy provider. For the development of the components, we will use Java with Application Development Framework (ADF) with Business Intelligence (BI) elements, in order to build interactive interfaces, easily configurable and accessible through mobile devices.

Created in online technology, on a cloud computing platform, the solution will be easily scalable and reproducible for customers, based on a standard platform that will be cloned and customized to answer the individual needs for trading sessions and reporting of each BRP. The prototype architecture (Fig.4.) consists in several models and components described below:

- ***Data model***. The system's entities will be modeled in a relational schema to enable fast and real time access to real data and information about the viability of renewable energy generation and performance of smart meters. An advanced Extract, Transform and Load (ETL) process will be used to gather data from heterogeneous sources (smart meters, intelligent devices, energy trading platforms) after a quick data profiling process like in [11]. The solution for data management is Oracle Database 12c in order to provide cloud computing facilities. Regarding the smart metering systems' data, the Oracle NoSQL Database in cloud computing will offer access for BRPs to consumers' data without investing in expensive IT&C infrastructure for Big Data solutions. At the present time in Romania there is no solution that can offer real time data and analysis on renewable energy or smart meters' data and we hope that the current project will provide a single access point to a platform that will contain the information needed to support inspired economic decisions.

- ***The forecasting, optimization and analysis models*** described in section 2 will be developed and implemented in Java on a cloud computing platform. The forecasting model will be developed based on artificial neural networks algorithms with good performance as demonstrated already in [12] and [13]. For optimization of supply/demand balance under network constraints, decomposition techniques will be utilized given complex nature of the problem.
- ***Presentation and reporting model*** will be developed in Java with Application Development Framework with Business intelligence elements in order to allow a flexible and interactive interface for real – time data analysis. The components will include dashboards, customized reports, pivot tables, charts, interactive maps that can be easily accessed through different devices like mobiles, laptops, PC tablets. The prototype will facilitate the access of the managers to relevant information to justify their strategic decisions regarding the trading activities, will minimize the time of decision making process through immediate access to information and aggregate reports, and will increase the relevance of information, as demonstrated in [14].

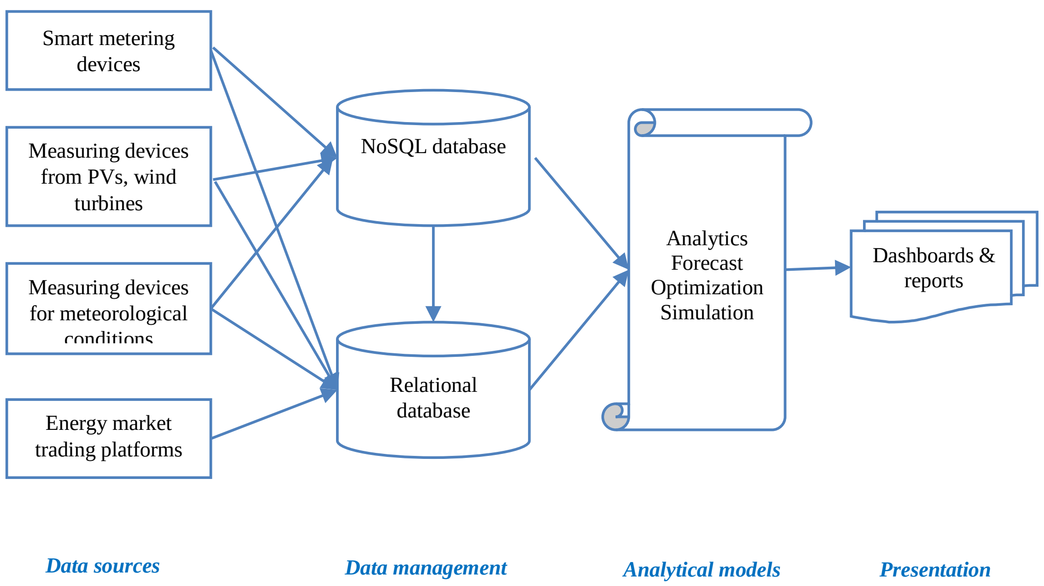

Fig.4. SMARTRADE prototype architecture

The prototype will be created on a flexible and scalable architecture, so that it can be further developed through the inclusion of components derived from technical improvements (as Internet of Things intelligent equipment, new measuring devices), in order to satisfy the beneficiaries' requirements on the long run. The implementation of the prototype will bring to the companies a competitive edge in the market share from existing competitors.

4 Technologies for informatics solution development

4.1 Databases & Cloud Computing

According to [15], NIST (National Institute of Standards and Technology) defines Cloud Computing as a model of computing architecture that enables on-demand network access to a multitude of resources shared between users. Resources refer to a wide range of items, like data stored in databases, functionalities and services offered by applications, storage capabilities and hardware support.

In a cloud computing architecture, all applications are controlled, managed, and served by a cloud server. Its data is replicated and preserved remotely as part of the cloud configuration. Table 1 presents some differences between standard and cloud computing architectures.

As detailed in [15] and [16], cloud computing has three service models that need to be virtualized as services:

- Infrastructure as a Service (IaaS) - is the main model in Cloud Computing and refers to sharing raw computing hardware over the network (e.g. Web-hosting);
- Software as a Service (SaaS) - users access applications provided by the cloud administrators (e.g. Web-based email, Google Docs);
- Platform as a Service (PaaS) - offers a range of software necessary to develop applications which will run on systems software and hardware provided by another company (e.g. Google Apps Engine).

Table 1 - Some differences between standard and cloud computing architecture

Standard computing architecture	**Cloud computing architecture**
Each entity maintain its own IT infrastructure	IT infrastructure is shared and used by multiple entities
Systems are heterogeneous and complex	The platform is homogeneous, simplified and unified controlled
Infrastructure is managed by specialists	Infrastructure is virtualized, optimized and well managed by specialists
Low-level support from the specialists	High-level support
Intensive usage of energetic resources for a high number of data centers	Optimized usage of energetic resources by aggregating data centers

As stated in [16], starting from these services a number of new ones have also emerged, such as: Database as a Service (DBaaS), Big Data as a Service (BDaaS), Storage as a Service (StaaS), and so on.

In the component architecture of database systems, the most important role it is held at the data layer by the databases. Cloud computing offers an efficient way of processing and managing large volumes of data, because big time philosophy involves storing and processing large data sets, inefficiently managed by conventional database systems and related software tools.

Oracle Database 12c is specifically designed for the cloud architecture. It offers a cloud solution that brings new features such as: providing database as a service in the cloud, optimization, integration and Big Data analysis, security facilities etc. [17].

4.2 Java framework

An application framework makes it easier to develop an enterprise application by offering specific functionalities, like: design patterns, database accessibility, error handling, easy compilation, versioning, debugging tools, maintenance tools etc. A recent study showed a Java framework ranking [18] which reveals the most popular Java frameworks in 2016: Maven, Java 8, IntelliJ IDEA, J2EE and Spring.

An important application development framework for J2EE is Oracle ADF, which will be used for develop the informatics solution for efficient trading activities on wholesale energy markets in Romania.

Oracle ADF (Application Development Framework) is a service-oriented architecture (SOA) for creating J2EE applications, which uses JSF (Java Server Faces) and it is implemented in Oracle JDeveloper IDE (Integrated Development Environment) [19]. ADF works as a cross-platform solution that allows developers to use the same services and security solutions across desktop, mobile, and web applications.

Figure 5 reveals Oracle ADF architecture, showing the main technologies used by each of the levels of a standard MVC (Model-View-Controller) informatics solution architecture.

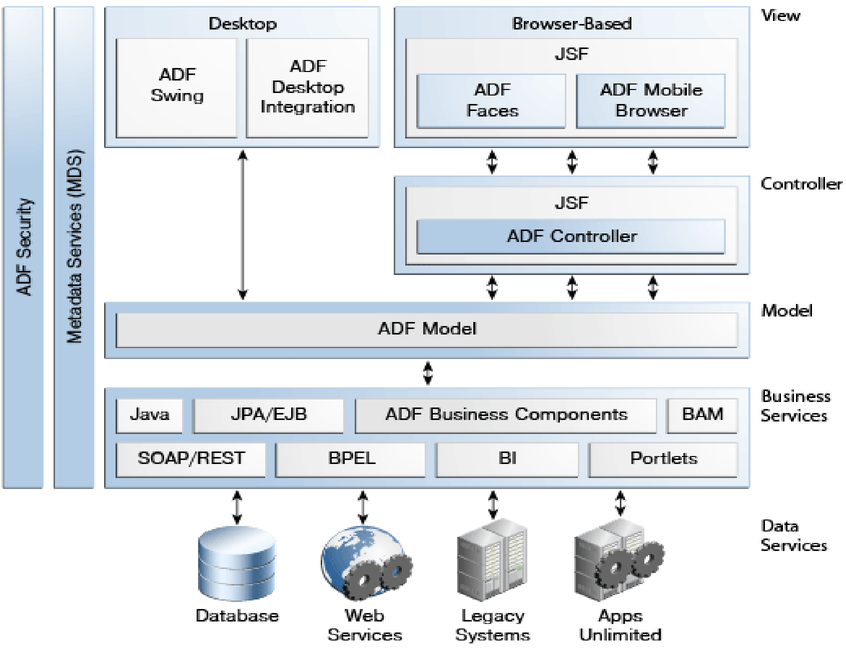

Fig.5. Oracle ADF architecture
Source: [19]

Analyzing the above figure, we discover the four layers of the ADF architecture and also the main ADF components which can be involved in a MVC solution:

- Business Services Layer: offers access to data from various sources and addresses business logic. Through ADF Business Components are provided basic functionalities and easy database interaction without having to use Java code;

- Model Layer: provides an abstraction layer that connects all the layers through ADF Binding;
- Controller Layer: uses ADF Controller in order to implement the flow of the web application;
- View Layer: provides the user interface of the application using the component ADF Faces.

5 Conclusions

The SMARTRADE prototype will be able to open new approaches, even after the project is finished, at the interdisciplinary level of the research field (informatics and energy) through models and proposed algorithms. Thus, each of the original models described will open new themes or approaches:

- Through the data model – because of the novelty character of the approached elements which derive from the Big Data paradigm for smart metering systems and IoT devices, we consider that the research in this field is still at its beginning, and the proposed model within the project can constitute a new ground point for the efficient and real time organization of data coming from smart metering systems;
- The estimation of prosumer/consumer behavior is an ever changing activity because of its equipment evolution, their possibility to generate power through own equipment, but also through the demographic and social changes. The forecast model proposed in this project will be subject to progressive improvements in order to keep pace with technical development and the evolution of prosumer/consumer behavior;
- The forecast model for energy generation will be subject to improvement in order to be also used by prosumers, so that they can estimate their self-generation capacity.

The virtual simulator of the prototype will be created on a flexible and scalable architecture, so that it can be further developed through the inclusion of components derived from technical improvements (as IoT devices), in order to satisfy the beneficiaries' requirements on the long run.

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