Data model for Demand Side Management

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Demand Side Management (DSM) is a portfolio of measures to improve the energy system mainly at the consumption level. In this paper we propose a data model for DSM stating from the optimization methods approach in SMARTRADE project from different perspectives of several entities that include: Transmission System Operator (TSO)/Distribution System Operators (DSOs) perspectives in case of security/reliability concerns: minimum amount of load (or generation) shedding; aggregators perspective in case of demand or generation shedding request: Which demand (or generators) should be shed?; consumers perspective: load shifting (time-of-use (ToU) tariffs) and optimum contract strategies with the aggregators (also known as balancing responsible parties- BRP) for load shedding.
Keywords: *data model, demand side management, optimization process, mixed integer linear programing, electricity consumption, load/generation shedding*

1 Introduction

DSM ranges from improving energy efficiency by using energy efficient products, over smart energy tariffs with incentives for certain consumption patterns, up to sophisticated real-time control of load and distributed energy resources [1]. DSM is an important function in energy management of the future smart grid, which provides support towards smart grid functionalities in various areas such as electricity market control and management, infrastructure, management of decentralized energy resources, etc. Controlling and influencing energy demand can reduce the overall peak load demand, reshape the demand profile and increase the grid sustainability by reducing the overall cost and carbon emission levels.

DSM is becoming more and more important in smart grids concept that allows consumers to make informed decisions regarding their energy consumption and helps the energy suppliers reduce the peak load demand and reshape the load profile [2]. DSM models for different time scales are presented in Fig. 1. For long-term perspective, the DSM provides improvement in energy efficiency; it enables direct load control in real time when necessary for the security and/or reliability of the power system.

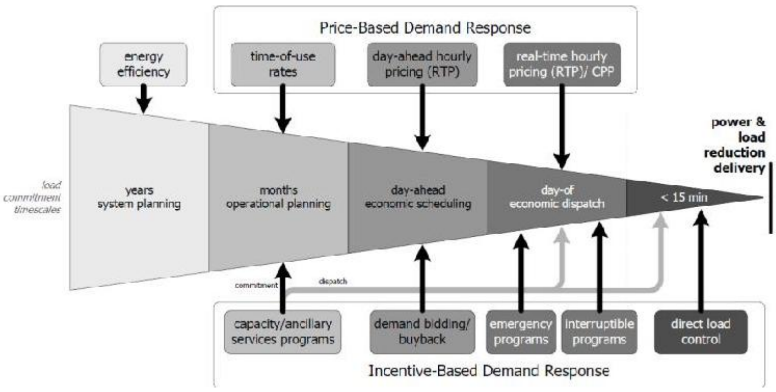

Fig. 1. DSM models for different time scales

Time-of-use tariff rates are among the initial implementation of DSM, which has been implemented in many countries for several years. Time-of-use tariff rates enable consumers who are willing to reduce consumption during periods when the total demand for electricity is highest (at peak load) to save money. Consumers who are subject to time-of-use rates can reduce their expenses by shifting their energy use to partial-peak or off-peak hours of the day. In order to benefit from time-of-use tarifffrates, the electricity meters of the consumers should be electronic and have the capability to stamp time according to rate periods (e.g., morning time, peak time, night time, etc.). Smart meters nowadays provide more than stamping time of use indeed. They provide messages from electricity suppliers, reading remotely and direct load control (electricity cut) via a telemetry. Smart meters are necessary for all types of price-based and incentive-based demand responses as illustrated in Fig. 1.

2 SMARTRADE Project in terms of DSM and electricity market

The research project “Intelligent system for trading on wholesale electricity market” (with acronym SMARTRADE) is supported by National Authority for Scientific Research and Innovation through European Regional Development Fund (ERDF). The main objective of the project is to design and develop an informatics prototype for forecasting, analysis and decision models mainly for all interested market participants (suppliers/producers) constituted as balance responsible parties (BRP) or aggregators, in order to estimate energy demand and generation in a suitable way for an efficient trading on the wholesale energy market. The prototype will be developed on a private cloud computing architecture and will be addressed to BRP and grid operators alike, especially to the Transmission System Operator and the Distribution System Operators, for estimation of the electricity demand and generation at the national or 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. Main scope of the project is to establish efficient trading offers on the energy market, based on business rules and decision models.

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 the electricity market. Supply and demand balance should satisfy transmission grid constraints in an optimum manner. Re-dispatching 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 and demand balance while satisfying grid 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. Modules of the SMARTRADE project prototype are presented in Fig. 2 as described in [7].

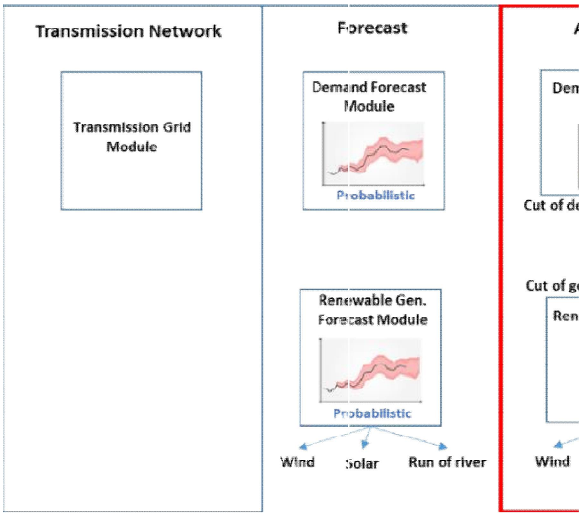

Fig. 2. Modules of the SMARTRADE project prototype [7]

The key component of the prototype is the aggregator module, as marked in Fig. 2. It is considered in modelling either demand or renewable generation shedding, as necessary. Demand and renewable generation aggregator moduleconsists in representing demand and renewable generation shedding capabilities for supply and demand balancing issue.

Aggregators are becoming one of the key players in electricity market along with other developments in the power sector including: maturation of the electricity markets; increase of distributed generation which are embedded in distribution grid (wind, PV, biomass and other renewable sources); smart meters implementation; transformation of some consumers into prosumers.

Initial electricity market structure in many countries worldwide include a wholesale market at high voltage level (i.e., transmission), as shown in Fig. 3. Given the developments described above, aggregators has started to take roles in this market by providing load or generation shedding services to TSO, as shown in Fig. 4. However, this will also introduce some complexities to the DSOs, particularly when demand (or generation) shedding is required at the distribution grid level. Main question for the DSO is: how would the demand or generation shedding affect the distribution system? For instance, if demand shedding is made on a distribution feeder which has several PV units generating power, voltage on the feeder may increase to unacceptable levels.

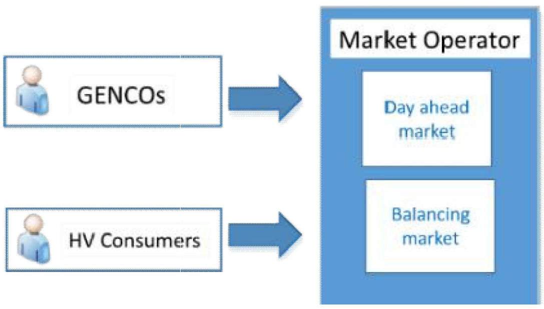

Fig. 3. Wholesale market at transmission level

Therefore, DSOs should essentially be included in the final decision of demand or generator shedding. Actually, there are discussions to develop a balancing market at the distribution grid level as well, in which aggregators can provide servicesdirectly to DSOs. Such a mechanism require coordination between the market operator, TSO, DSOs, aggregators and other players, as illustrated in Fig. 5. In conclusion, aggregators are expected to be one of the key players which provide demand and generation shedding services to TSO and DSOs in the future electricity markets. Therefore, aggregators are considered as a separate module in the SMARTRADE project prototype.

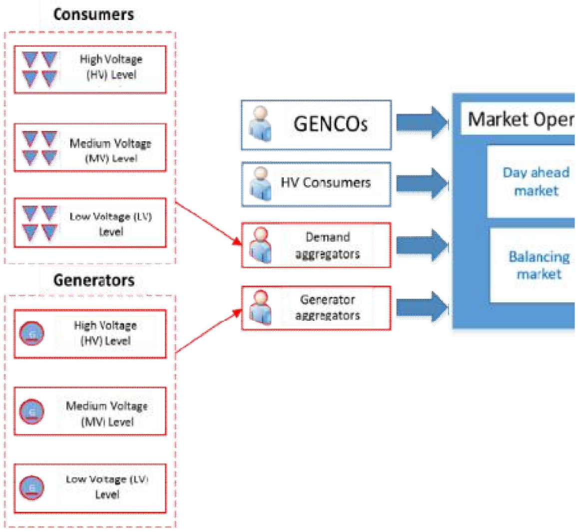

Fig. 4. Wholesale market at transmission grid level

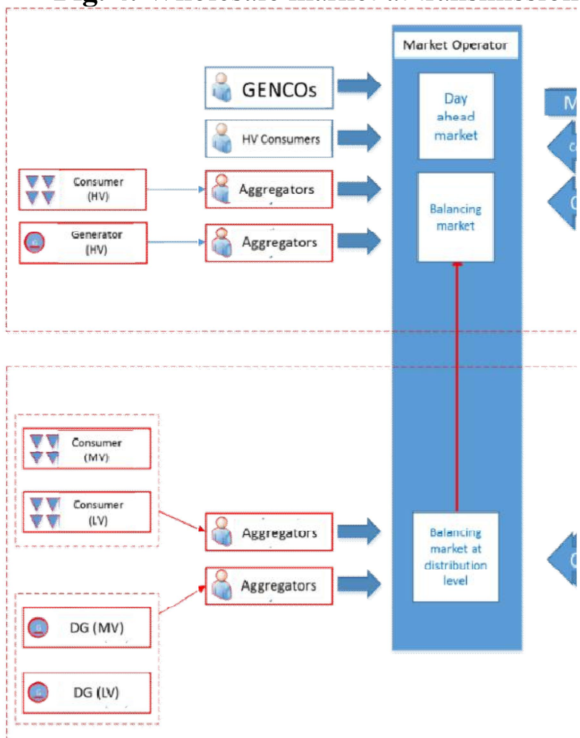

Fig. 5. Balancing market at the distribution grid level

3 Optimization methods in DSM process and proposed approach in SMARTRADE project

DSM concept is an optimization process inherently. Therefore, the optimization processes from the perspectives of market players include:

- From TSO/DSOs perspectives → In case of security/reliability concerns:
    - Minimum amount of load (or generation) shedding;

- From aggregators perspective → In case of demand or generation shedding request:
  - Which demand (or generators) should be shed?;
- From consumers perspective:
  - Load shifting (time-of-use tariffs);
  - Optimum contract strategies with the aggregators (load shedding).

Essentially, each market player should develop their optimization methods according to their objective function.

In the SMARTRADE project, perspectives of both TSO/DSOs and aggregators will be considered. Also SMARTRADE project will address optimizing load (or generation) shedding from TSO perspective, as illustrated in Fig. 4. The word not "minimizing", but "optimizing" of shedding is utilized due to fact that shedding decision is based on optimizing the load shedding (or generator) bids of the aggregators taking into account constraint of transmission system. If a TSO requires load or generation shedding to relax the power system which is subjected to network constraints, it should optimize this request based on cost of load or generation shedding. Bids from the aggregators are basis for determining the shedding cost.

Load or generator shedding could be considered in both operation and planning problem. In the planning problem (from day-ahead planning to long-term investment planning), market simulation gives commitment of the generators based on merit order, when the network constraints are ignored [6]. Objective function of the market simulation is minimizing total cost of generation. Generation of renewables, like wind power plants, PVs, and run-of-river hydraulic power plants are assumed as negative generation. A corresponding cost is defined for shedding the generation from renewables, in case of necessity due to technical constraints.

Technical constraints could be: i) overloading on the transmission branches and ii) N-1 contingency criterion (the rule according to which after one network element (line, transformer) failure, the elements remaining in operation within TSO's responsibility area after a contingency from the contingency list must be capable of accommodating the new operational situation without violating operational security limits).

Shedding cost of renewables is determined from the bids of aggregators who are assumed to have contracts with renewable generation sources and have capability of shedding the load (i.e., already equipped with telemetry infrastructure, etc.). If total generation is higher than load at certain hours, market simulation essentially proposes shedding the renewable generation starting from the minimum cost, if the cost of shedding generation from renewable sources is higher than that of conventional sources.

Market simulation result is given as input to the network simulation by the TSO, as illustrated in Fig. 6. Network simulation re-dispatches the conventional generators from their initial dispatch levels proposed by the market simulation results, based on either transmission constraints or spinning reserve requirements or both. Costs of generator and load shedding is considered in the network simulations as well as market simulation. Network simulation will determine optimum solution considering network constraints and necessary re-dispatches and/or load and/or generator shedding.

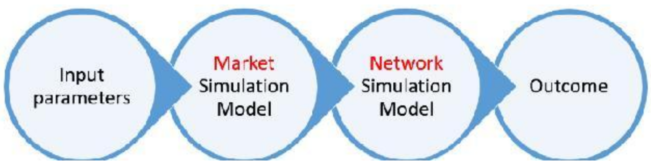

Fig. 6. Sequence simulation approach (market simulation → network simulation)

Both market simulation and network simulation problems are dynamic optimization problems along a time interval (e.g., 24 hour of a day for day-ahead planning or 8760 hour of a year for one year planning). They are both mixed-integer linear programming (MILP) optimization problems.
Decomposition techniques will be utilized to get optimum solution iteratively, as illustrated in Fig. 7. Conceptual design of the proposed solution (market simulation → network simulation) is presented in details in **Error! Reference source not found.** . It may be assumed that there is no need for generator and/or load shedding in the market simulation. However, in case of total generation of renewables is higher than total load at certain hours, bids of aggregators could essentially be considered in market simulation as well. Similarly, if the total capacity of generation resources including renewables are less than total load at certain hours, load shedding could be considered based on bids of aggregators.

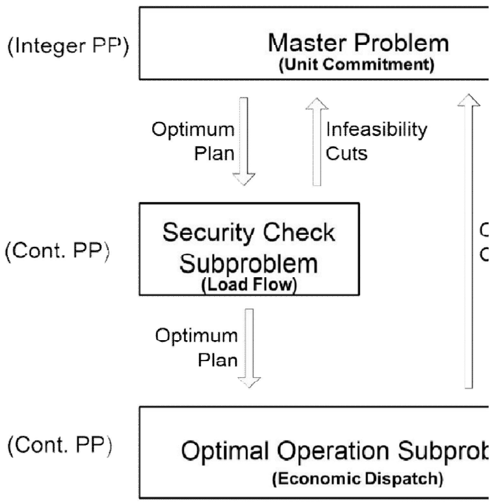

Fig. 7. Decomposition technique for iterative calculation of the optimum solution in network simulation

Load or generator shedding bids of the aggregators should be determined based on strategic decisions of the aggregators. This requires aggregators to define optimization processes. The aggregator bids, which are input to the market and network simulations of TSOare assumed to be identified by the aggregators in these modules.
Handling storage devices plays an important role in DSM; they can be categorized mainly as follows:

- Hydraulic power plants (HPP) which has storage dam:
  - Only generation;
- Pump storage hydraulic power plants:
  - Generation and consumption;
- Batteries:
  - Generation and consumption;
- Other storage devices (hydrogen, etc.).

All types of storages are subjected to energy constraints. For example, an HPP which has a large storage dam has a long-term energy constraint. That is, its energy production level is limited by its capacity stored in the dam. For pump storage power plants, energy constraint is rather on short-term horizon. Energy production cycle may be less than a day depending on the physical dimension of its storage, as illustrated by an example in Fig. [78]. Energy constraints of the batteries and other storage devices are even shorter in terms of duration.

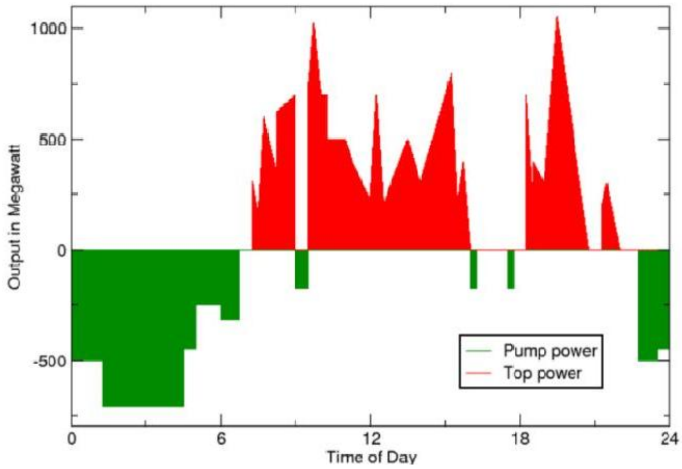

Fig. 8. Generating and pumping cycle of a pump storage power plant

In the SMARTRADE project, large dam HPPs and pump storages are assumed individual players in the market. However, battery and other storage devices are assumed to play in the market through the aggregators.

Cyclic efficiency of the batteries will be considered in the model. Efficiency of the battery devices will be assumed to be constant for short-term simulations, like one day, one week, etc. However, efficiency evolution of batteriesdue to charging and discharging along their lifetime will be considered for long-term simulations (one year and beyond).

DSM will be assumed to be provided by aggregators which will be modelled by demand aggregator module and generation aggregator module, as presented in [7]. Main data inputs to these modules include: aggregated time series demand, which can be shed by aggregator upon request from the TSO; time series bids of aggregators for demand shedding; aggregated time series generation, which can be shed by aggregator upon request from the TSO; time series bids of aggregators for generator shedding; aggregated storage (battery) capacity; energy constraints and cyclic efficiency of the batteries; time series bids of aggregators for storage charging and discharging periods will be utilized for demand and generator shedding bids, respectively.

4 Data model for DSM

First stage of the data model for DSM presented in Fig. 9 contains the following main tables: T_ELECTRICITY_SUPPLIER withdata regarding the electricity supplier; T_SUPPLIER_MARKET withdata regarding wholesale electricity markets' participation of the supplier; T_ PROFILES for consumers' profiles determined by the electricity supplier; T_CONSUMER with data regarding consumers; T_CONSUMER_PLACE depicting place for consumption with mention that each consumer may have one or multiple consumption places; T_CONSUMER_PLACE_DETAILS showing consumer's place detailed information regarding occupancy and generation sources; T_TARIFFS for electricity tariffs' schemas applied by electricity supplier to their consumers; T_CONSUMER_TARIFFS with electricity tariffs' schemas applied to a specific consumer; T_METER for smart meters installed at consumer's side; T_METER_READINGS for smart meters reading transmitted to the electricity supplier; T_ELECTRIC_APPLIANCES for electric appliances installed at consumer's side; T_APPLIANCES_TYPES for electric appliances' detailed information; T_ APPLIANCE_READING for electric appliances' reading transmitted to the electricity supplier.

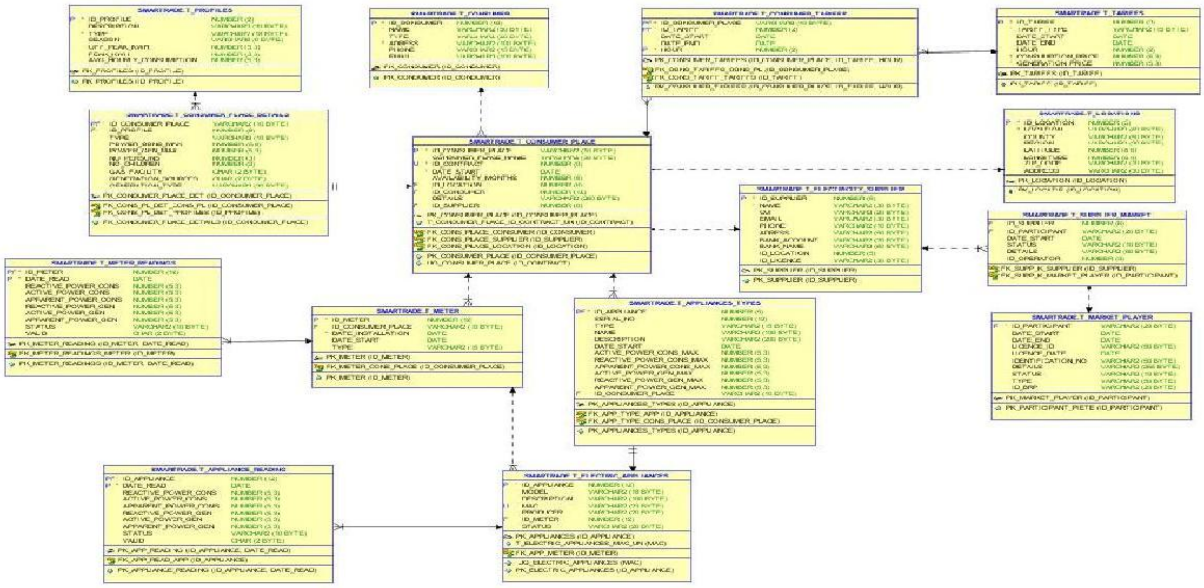

Fig. 9. Data model for DSM

The data model allow the monitoring and achieving of specific activities for DSM measures. However, it will be continuously refined by inclusion of other measures and concepts (i.e. IoT).

5 Conclusions

In this paper proposed a data model for DSM stating from the optimization methods approach in SMARTRADE project from different perspectives of several entities that include: TSO/DSOs, aggregators, consumers' perspective. Data model contains tables related to the electricity supplier; wholesale electricity markets' participation of the supplier; consumers' profiles determined by the electricity supplier; data regarding consumers; depicting place for consumption; consumers' place detailed information regarding occupancy and generation sources; electricity tariffs' schemas applied by electricity supplier to their consumers; electricity tariffs' schemas applied to a specific consumer; smart meters data installed at consumer's side; smart meters reading transmitted to the electricity supplier; electric appliances installed at consumer's side; electric appliances' detailed information; electric appliances' reading transmitted to the electricity supplier.

6 Acknowledgment

This paper presents the scientific results of the project "Intelligent system for trading on wholesale electricity market" (SMARTRADE), co-financed by the European Regional Development Fund (ERDF), through the Competitiveness Operational Programme (COP) 2014-2020, priority axis 1 – Research, technological development and innovation (RD&I) to support economic competitiveness and business development, Action 1.1.4 - Attracting high-level personnel from abroad in order to enhance the RD capacity, contract ID P_37_418, no. 62/05.09.2016, beneficiary: The Bucharest University of Economic Studies.

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