ASSESSMENT OF A BUSINESS MODEL FOR POWER EXCHANGE BETWEEN VESSELS AND ASHORE ELECTRICITY DISTRIBUTION NETWORK

Andrei Z. Morch
SINTEF Energiforskning AS
NO-7465 Trondheim, Norway
azm@sintef.no

Damien Féger
Snecma
FR-27208 Vernon, France
damien.feger@snecma.fr

Nicolai Feilberg
SINTEF Energiforskning AS
NO-7465 Trondheim, Norway
nicolai.feilberg@sintef.no

INTRODUCTION

Reduction of emissions, which are currently generated by global shipping, makes the shipping operators to search for new innovative solutions. One concept that is being promoted by a number of ports is so-called “cold ironing”, when electricity, which is necessary for covering the vessel’s own electricity demand, including its “hotel” and cargo handling requirements, is supplied via an electric connection to the conventional electricity distribution network in the given harbour of call. Considering the steady increasing of price for petroleum products, the cold ironing may become a cost-efficient alternative for many shipowners in the close future.

Cold ironing operations have already been implemented for a number of cruise liners, while carriers of Liquefied Natural Gas (LNG) are expected to be the next target group. Since the available generation capacity on big Liquefied Natural Gas (LNG) tankers is about 5-10 MW, it can be alternatively traded on deregulated electricity markets (spot markets or balancing markets), when the prices are favourable. Implementation of these schemes has been however limited due to absence of standard physical power interfaces between vessels and harbour terminals.

Figure 1 A typical power line connector, which is used today

Establishment of a connection between a vessel and a harbour is very time consuming and usually requires a crane and a significant amount of manual handling by the crew and the terminal operator. Figure 1 shows a typical power line connector, which is used today.

The paper is based on results and findings from a European Project PLUG[1] (Power Generation during Loading & Unloading), which gathers multidisciplinary expertise from both shipping and electricity industry. The main objective of the project is to develop and put on the market a standard physical power interface between cargo vessels and electricity distribution network at harbour terminals. The power interface can be connected and disconnected in few minutes, meaning that an LNG carrier may be able to exchange power with the local grid during at least 19 hours during each call, while a Container Carrier (CC) may be able to stay connected as long as the vessel remains in quay, basically 24 hours. The manual handling of the planned interface will be minimised, and the connection will allow either:

- Use vessel's generators to feed power into the local electricity distribution network
- Use local network to supply the vessel's electricity demand during loading/unloading

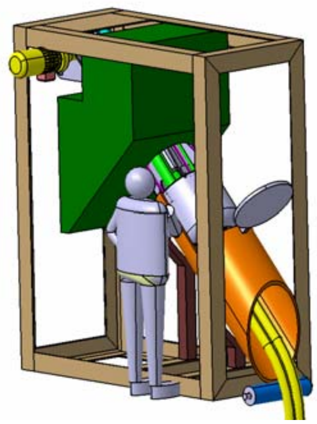

Figure 2 A simplified overview of the concept interface, installed on a vessel. Source: Stäubli SCA

Figure 2 presents a simplified overview of the concept interface, installed on a vessel. The manual handling of the planned interface will be minimised, so from a crew's point of view, operations are as simple as for a mooring line. Among other technical requirements can be mentioned the following:

- Establishment of the connection: 15 minutes.
- Safe emergency release in less than 60 seconds
- 8 MW / 6600 V capability for cold ironing, scalable to up to 25 MW for power generation towards the shore
- Watertight (20 m) connector when disconnected
- Seamless transfer between on board and on shore supply

ASSUMPTIONS AND LIMITATIONS OF THE STUDY

The modern deregulated power market is very flexible and provides a multitude of opportunities for development of new services. The present study attempts to narrow the scope of the study by

[1] www.sintef.no/plug

focusing on scenarios which are the most relevant, and especially the most probable within the existing market organisation, based on the available input data and constraints as, for example, limitations of the available generation capacity onboard, the terminal's capacity etc. The roles and responsibilities of different actors in the electricity market may vary from country to country depending on if and how the electricity supply industry is deregulated. The present study is primarily based on the definitions of the actors, their roles and responsibilities, which are used in the Norwegian power market. In order to make the scenarios more realistic and doable, it is also assumed that implementation of these scenarios will require:

- None or minimum modifications, to the existing rules, regulations and information exchanging routines
- Creation of none or minimum new market actors
- That the existing actors will continue to carry out their core functions

Two-way electricity exchange between a vessel and a harbour, by using a PLUG-type connection is a new and innovative service. Therefore it has been difficult to gather correct input data for the simulations especially when it comes to payment for the network services, which would allow both consumption and feeding of electricity into the network. The paper refers to the historical spot prices and network tariffs (2006) for Hammerfest in the Northern Norway [2]. Furthermore, the study refers to the Snøhvit-project on Melkøya island outside Hammerfest in Northern Norway, which is Europe's first export facility for liquefied natural gas (LNG), as an example and reference point for the input data. In order to make the proposed business model more applicable it is made more generic and does not directly correspond to the present organisation at Melkøya island.

SOFTWARE DEMONSTRATOR "LINK TO MARKET"

The electricity system in Norway is deregulated - the liberalisation of the market implied a separation of tasks related to the trade and transport of electric energy. The production and trade in electric energy have been liberalized while the transmission and distribution are maintained as a monopoly. According to the Energy Law, the electricity sales and the electricity transport of integrated utilities must be completely unbundled with separate accounting for production, trading and transmission. The electricity spot-market[2] is operated by NordPool, the Nordic Power Exchange, and is a so-called "day-ahead" type, when the electricity spot prices with one hour resolution are known one day beforehand. After assessment of alternative target markets, the electricity spot-market was identified as the most relevant target market for PLUG [1].

The growing price volatility requires a frequent decision-making

The growing price volatility and scarce generation capacity are probably the most known features of deregulated electricity markets. Figure 3 shows variation of the system price at NordPool for 2007. The registered proportion between the lowest (8,8 Euro/MWh) and the highest (49,67 Euro/MWh) price during the given period was more than 5 times.

[2] www.nordpool.com

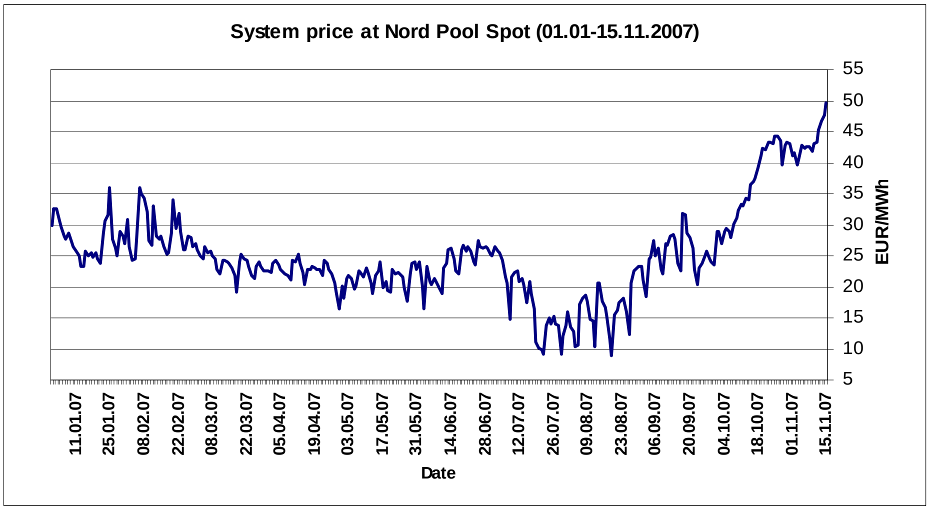

Figure 3 Electricity System Price for 2007. Source: NordPool ASA

An efficient participation of a vessel or a group of them in the spot market environment requires a frequent decision making and regular developing of generation schedules, based on day-ahead electricity spot prices. SINTEF Energiforskning AS developed for these purposes a Demonstrator – a software decision-support tool on a local level, which can be adapted to technical characteristics of a particular vessel in a particular port of call. Figure 4 shows the Demonstrator's interface.

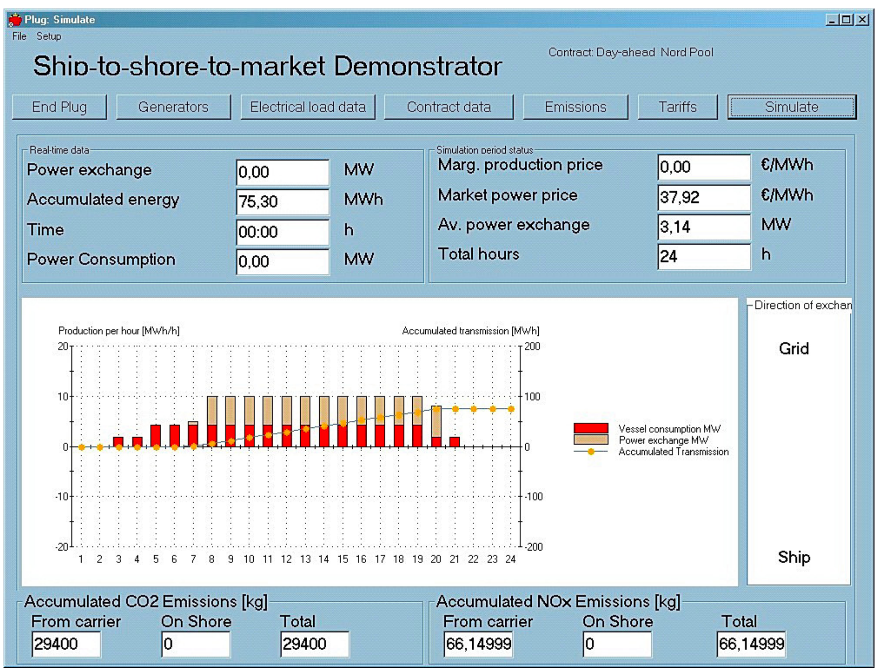

Figure 4 Link to market software.

Based on a set of given input data (see the next section) the Demonstrator develops the most feasible schedule for generation onboard and electricity exchange between the vessel and harbour. The schedule normally has 24-hours duration for a day-ahead generation planning, but it is also possible to run simulations for a whole year, based on historical prices.

The Demonstrator is not meant to be a bidding tool nor a portfolio-optimisation tool, since these activities are normally performed by Electricity Brokers.

Examples of the simulation

To perform the simulations of electricity exchange schedules and calculations, certain information from the user/carrier is necessary as input to the Demonstrator software. This input data is divided into five categories:

- **Generator data**: availability of the vessels' electricity production and costs of the generation.
- **Energy demand data:** the vessel's own electricity demand during a call
- **Contract data:** prices from the day ahead or other electricity markets
- **Distribution network tariff data**: costs of the network services for both export and import of electricity
- **Emission data:** emissions from the vessel's generation, compared with emissions in the port of call

For each category data is displayed and can be edited in a separate window (user interface). These windows can be reached from the main window where the simulation is displayed.

During a call, the tanker has an electricity demand covering its own electricity consumption (cargo pumps, air conditioning etc.). Normally the demand will depend upon several internal and external factors as, for example, weather conditions in the port and vary accordingly. For the sake of simplicity the study uses a typical load curve for LNG vessels, which is shown in Figure 5.

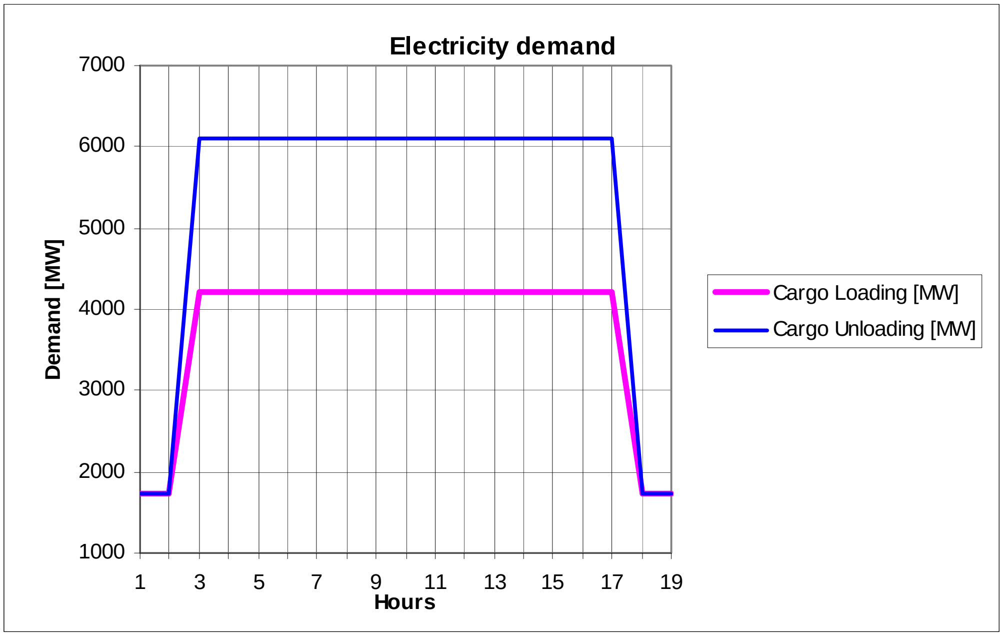

Figure 5 The vessel's own electricity demand during a call. Source: Wavespec Ltd

Duration of a call is normally about 19 hours, where the vessel stands idle two hours before and after loading, and its own demand is respectively reduced.

In order to study interaction between the spot market and a vessel, several simulations have been made, based on historical electricity prices for 2006. The sample simulation example, shown in Figure 6, uses electricity spot prices from the 9th of January of 2006, where it was a very high price variation during one day. The simulation is related to an LNG vessel with three auxiliary generators with different generation capacity and price. Duration of the call and respectively the vessel's electricity demand is 19 hours.

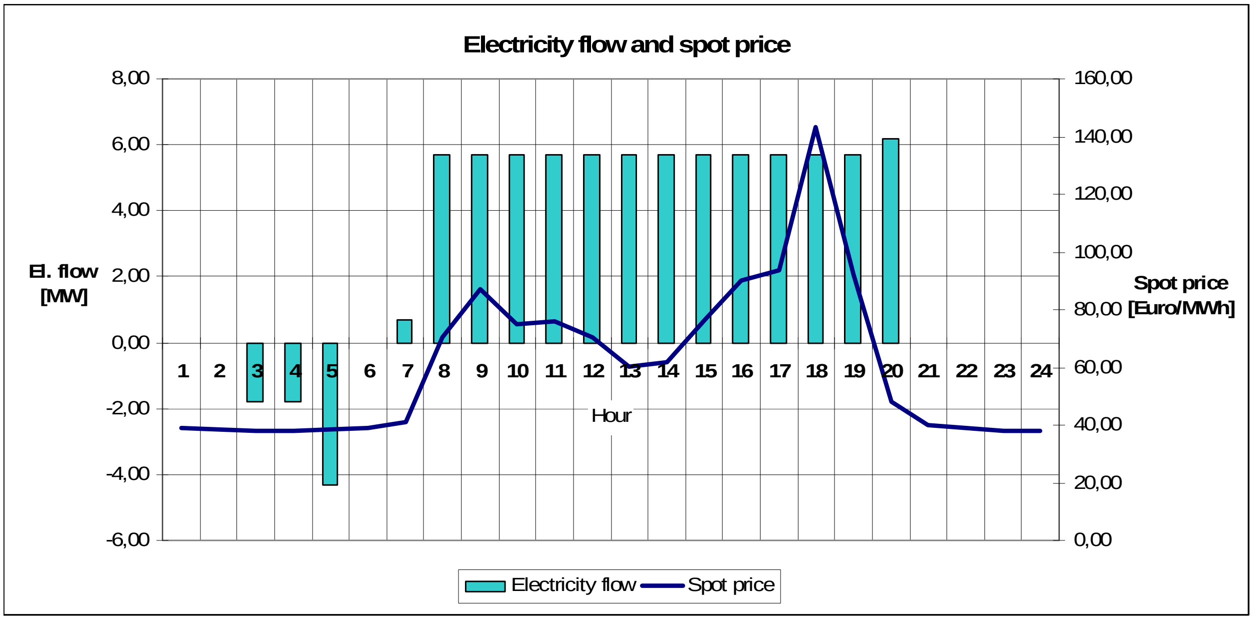

Figure 6 Electricity exchange between the spot market and vessel during high spot price volatility period.

Connection between the vessel and the local electricity network is established at 03:00. From 03:00 until 05:00 the electricity spot prices ashore are lower then the generation costs, so the vessel imports electricity from the conventional network (the electricity flow is negative). After hour 6 the spot prices start to raise and access the own generation costs (the electricity flow is equal to zero). The vessel starts Generator 1 with the lowest generation costs in order to cover the own consumption. The further raising of the electricity price leads to activation of all three generators. The generators start to supply electricity to the vessel and simultaneously export the surplus capacity to the local net (the electricity flow is positive). This lasts until hour 20, when the falling spot prices make the export of electricity unprofitable. The vessel accordingly deactivates Generator 3 with the highest production costs at hour 20 and stops export of electricity at hour 21.

The simulations have shown that an efficient operation in the spot market environment requires a frequent decision making and regular developing of generation schedules based on day-ahead electricity spot prices. The main conclusion, which can be derived from the simulation examples that the generation schedules are going to be influenced a lot by the price development ashore and likely to have a strong variation even within a fairly short time frame.

DEVELOPMENT OF PLUG BUSINESS MODEL

Liberalised electricity market is a multi-actor business network, where a successful assessment and further implementation of new business ideas requires a clear overview over all processes and involved actors. Therefore the study applies the *e3value* methodology – a multi-actor approach for developing business models, taking into consideration the importance of economic value for all actors involved.

Development of PLUG business model

The *e3value* methodology has been developed at Free University of Amsterdam by Dr Jaap Gordijn and Prof Hans Akkermans[3] and successfully applied in several European R&D projects. In particular, the e^3*value* methodology provides modelling concepts for showing which parties exchange things of *economic value* with whom, *and* expect *what* in return. Actors exchange *objects of economic value,* which can be physical objects, services or fees. The methodology models only things of *economic value* and not, for example, information required for business processes. The scope of this paper does not allow giving a comprehensive description of the methodology, but the interested readers are advised to read a description of the methodology [4].

The *e3value* methodology consists of several consequent steps, so the first step in the study was mapping of all relevant actors, their business activities and further definition of value exchanges between them as it is shown in Table 1.

Table 1 PLUG – an overview over actors and their business activities in the scenario

ID	Actor	Activities
DSO	Distribution System Operator	**Electricity Transport and distribution:** DSO on deregulated electricity markets provides electricity transmission services to Final Customers and to Electricity Generators (Vessel).
		Metering and Billing: DSO is responsible for metering of electricity, consumed by Final Customer and fed into the network by Generators (here Vessel). The DSO is also responsible for the billing routines.
FC	Final Customer	**Consumption of Electricity:** Final Customers consume electricity for their needs.
EB	Electricity Broker	**Trading Electricity:** Electricity Broker sells electricity to Final Customers, purchases electricity from Generators (her Vessel) and trades it on the Electricity Exchange (Market Operator).
V	Vessel	**Electricity Consumption**: The Vessel has electricity demand for its own operation. When the Vessel uses PLUG in a harbour, the demand can be covered by own production or by electricity from

[3] http://www.e3value.com/

ID	Actor	Activities
		the conventional grid ashore.
		Electricity Generation: The Vessel generates electricity onboard. The production can be used for covering of the own demand and export to the conventional electricity grid ashore, when the surplice power is soled to the Electricity Broker.
FS	Fuel Supplier	**Supply of the fuel:** The actor sells fuel to the Vessel's own generation.
MO	Market Operator	**Operation of the Market**: MO provides possibility for trading electricity and sets the market price (spot-price).
TSO	Transmission System Operator	**Balancing services and access to the main grid:** TSO provides access to the main grid and thus the electricity market.

Based on this information, an *e3value* business model was constructed, which is shown in Figure 7. (The yellow and light yellow boxes in the Figure include the Legend.) The model shows for example, that Distribution System Operator (DSO) is a market segment, which has Electricity Transmission and Metering and Billing as its two value activities. DSO offers electricity transmission services to Final Customer (FC) and Vessel (V) as a value objects and receives transmission fees (distribution network tariffs and feeding tariffs) from the respectively Final Customer and Vessel. Value objects, are offered and requested via value ports, depicted by triangular arrows.

The arrow in a value port shows whether a particular actor requests or delivers an object of value to or from its environment. These ports are grouped into value interfaces, depicted by small rounded boxes surrounding two or more value ports. Such a value interface represents that objects are requested/offered only in combination, and fulfils two modelling purposes:

- Value interface models economic reciprocity as, for example, transmission services in exchange for transmission fees (tariffs)
- Value interface may represent bundling of several products or services, saying that two or more value objects are offered (or requested) only in combination.

Additionally the model includes a scenario path (stippled line) that consists of one or more scenario segments, related by connection elements, and start- and stop stimuli. Scenario path indicates via which value interfaces objects of value must be exchanged, as a result of a start stimulus, or as a result of exchanges via other value interfaces. A scenario path starts with a start stimulus, which represents a consumer's demand.

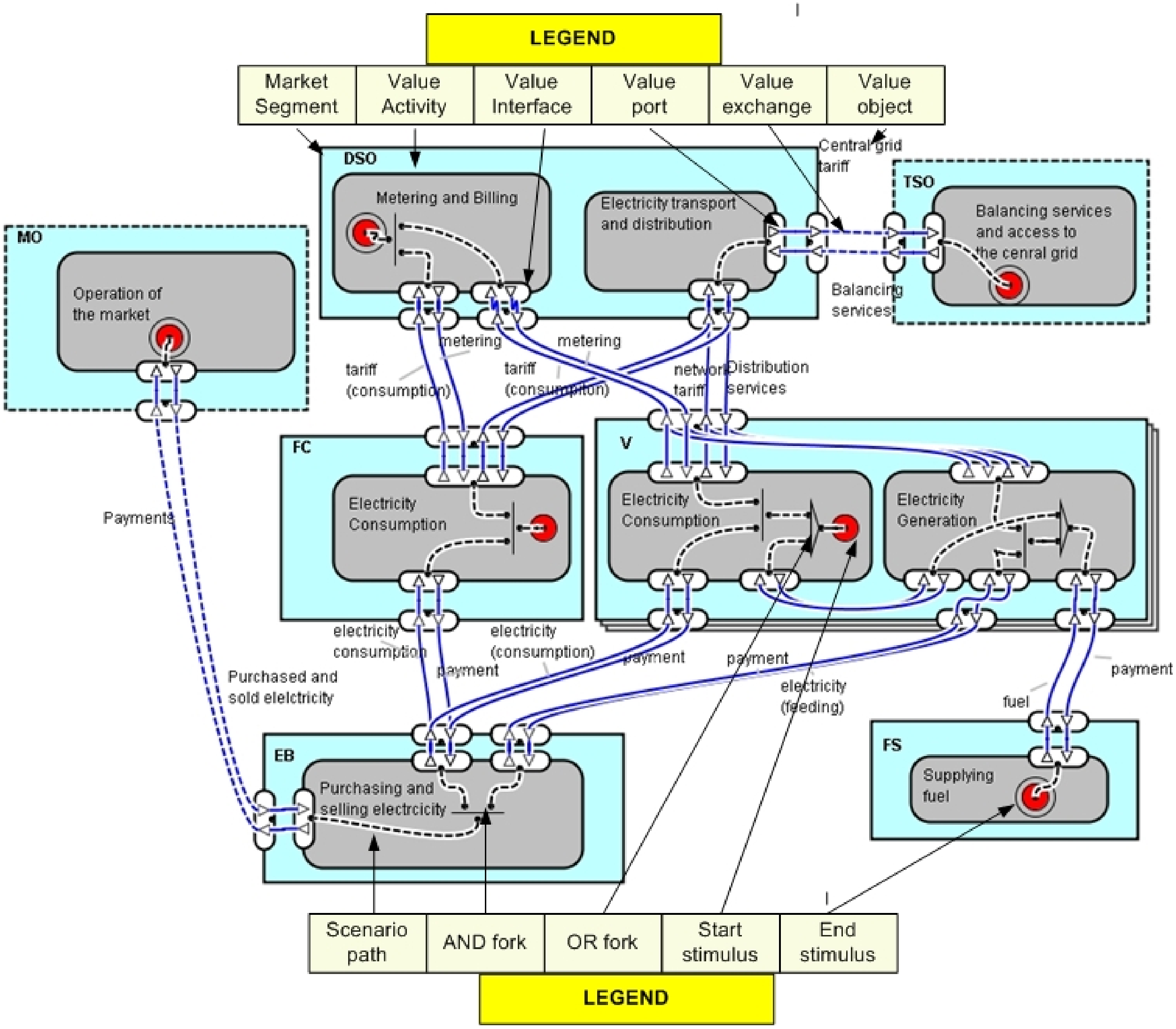

Figure 7 PLUG business mode, developed with e3value editor (www.e3value.com)

The scenario path includes connections and so-called forks (*AND*, *OR*), which are used to relate individual scenario segments. In our example the scenario starts simultaneously in two segments:

- FC demands for electricity *AND* transmission services, which are necessary in order to deliver the electricity on the customer's doorstep
- V demands electricity for its own consumption, which can be covered by own Electricity Generation *OR* by importing from Electricity Broker (EB). In this case the Vessel has also (*AND*) to purchase distribution network services from DSO and pay a network tariff for it.

The last segment(s) of a scenario path is connected to a stop stimulus. A stop stimulus indicates that the scenario path ends.

Assessment of the PLUG business scenario

Assessment of a business scenario focuses on the question whether a chosen business scenario is feasible from economic point of view and whether it is profitable for each actor involved. For doing this, the study chooses 2006 as reference year and quantifies the value exchanges between the actors in order to calculate cash flows for each actor in the scenario.

In the present situation, calculation of the cash flows is complicated because the Vessel has to compare the generation prices with day-ahead spot prices hour by hour and prepare an operation schedule for each call in a harbour, as it is shown earlier in Figure 6. The Vessel's demand is determined and has to be covered in two ways:

- By its own generation if the spot prices are higher than its own generation costs. The surplus electricity from its own generation is sold on the spot market, when it is feasible.
- By import from the ashore grid, if the spot-prices are lower than its own generation costs.

The Demonstrator software was used for development of one-year long operation schedule, referring to electricity spot-prices for 2006 in the Northern Norway [5] and flat fuel prices for 2006. The schedule based on 19-hour long calls, which are planned each fifth day during the whole year (73 calls totally).

Normally calculation of the profitability should include value exchange for all the present actors. In the writing moment it was difficult to identify a distribution network tariff, which would allow both consumption and feeding electricity into the network for a vessel in a harbour, and how this would influence DSOs costs for the TSO. Therefore the calculation used two separate network tariffs, which were used by Hammerfest Energi in 2006; one for feeding (0,35 Euro/MWh) and another tariff for interruptible consumption (22kV), which is presented in Table 1.

Table 2Network tariffs and charges, related to interruptible electricity consumption (2006). Sources: NVE [2] and Hammerfest Energi AS

Description	**Value**
Constant charge	1.062,00 Euro pr year
Energy charge	7,50 Euro/MWh
Capacity charge	23.750,00 Euro/MW pr year

The vessel's own demand is the same as it is presented in Figure 5. The simulation used three different generation prices for the vessel:

- 30 Euro/MWh for the generator with 5 MW capacity
- 35 Euro/MWh for the generator with 3 MW generation capacity
- 40 Euro/MWh for the generation with 2 MW generation capacity

The simulation results for 2006 are presented in Table 3.

Table 3 Summary of the simulation results for 2006

Title	**Value**
Electricity export from the Vessel to the electricity market ashore	7.703,90 MWh
Electricity import from the electricity market ashore to the Vessel	8,60 MWh

Gross revenues for the electricity export	396.724,83 Euro
Fuel costs for the exported power	270.654,00 Euro
Network tariff costs for feeding and consumption	2.760,86 Euro
Total expected incomes pr year	123.309,97 Euro

The calculation above did not consider the constant charge and the capacity charge for electricity consumption, simply because it is unclear if these costs should be assigned to the Vessel or another actor. If they would be assigned to the vessel, it might be more feasible to avoid consumption from the conventional grid at all.

CONCLUSIONS AND DISCUSSION

Assessment of the business model provided quite surprising results, showing that it would be fairly profitable to export surplus electricity generation from a vessel to the conventional electricity market ashore. These results are mostly caused by the low fuel prices in 2006 and high distribution network tariffs for the consumption. The capacity charge is simply prohibitively high for this type of consumption. In case the vessel's operator would have to pay the capacity charge as well as a regular industrial customer, it would be virtually impossible to import electricity. However, as has been mentioned earlier, this is a very specific case, which is likely to require development of a special tariff for combined electricity consumption and feeding. This tariff should also consider that the vessel is very flexible and can switch between consumption and generation of electricity.

The study has shown that running a profitable electricity exchange between the vessel and the electricity market will require a frequent development of the generation schedules. Implementation of PLUG interface will also require significant investments in the harbour's infrastructure, but at the same time operation of a single vessel would bring considerable revenues in 2006. Considering a reasonable lifetime for the necessary additional infrastructure, these revenues are likely to justify the investment.

Furthermore, it is clear that the recent development of the petroleum prices makes it necessary to run new simulations.

REFERENCES

[1] Sigrun Kavli Mindeberg and Andrei Z. Morch *"D15: Data Exchange Study and Market Demonstrator*" Project Report. SINTEF Energiforskning AS, January 2008 (downloadable from www.sintef.no/plug)

[2] Sætrang I., Statistikk over netlleie i regional- og distribusjonsnettet 2006. Norges vassdrags- og energidirektoratet. April 2006. ISSN 1501-2840

[3] Information about distribution network tariffs. Hammerfest Energy AS www.hammerfestenergi.no

[4] Jaap Gordijn et.al. *"D5.3 DVC e-business scenario analysis tool. Version 2"* OBELIX project deliverable (downloadable at www.cs.vu.nl/~obelix/)
[5] Historical spot prices from www.nordpool.com

ACKNOWLEDGEMENTS

This paper is based on the results and findings from Power Generation during Loading & Unloading project (PLUG) Specific Targeted Research Project (STREP) in the European Sixth Framework Program. The project is partially financed by the European Commission.