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East West Cross Border Electricity Trade enabled by Wide area measurement and control

6. Power Engineering

SUMMARY

Motivated by the price difference between the Western and Eastern European electricity markets technological options for interconnections and economic models for the evaluation of the market behaviors are under general discussion. This paper discusses different options to realize the technical connection between the East and West European power Systems, i.e. a direct synchronization of subsystems of IPS to the UCTE system. All interconnection options need to have a suitable monitoring and control system, i.e. interconnection with SCADA/EMS systems in both regions. It is proposed to install a "Hyper SCADA/EMS" in addition to the application of a phasor measurement unit based wide area monitoring and control system in the major transmission paths for energy export. For the evaluation of the market opening in terms of market price development the second of this paper outlines an economic evaluation model, based on two Merit-Oder-Curves, to describe the electricity price evolution in the East and West European electricity markets. The calculation shows revenues resulting out of energy trading and the yearly profit out of interconnection between Western and Eastern European electricity markets.

KEYWORDS

Interconnected systems, Hyper SCADA, wide area measurement and control, phasor measurement units, energy market analysis, merit order curve, economic modeling

1. INTRODUCTION

In the light of the current status of the liberalization of the electricity market in Europe the high demand of electricity in Western Europe can be considered to become critical. Especially in Germany the forecast for the next two decade shows an increase in demanded production capacity of around 20 GW electrical power. Whether this need will be covered by newly commissioned power plants in Germany or provided by cross border transmissions from adjacent countries is a question of economical and technological feasibility. However, one option can be seen in the utilization of the Eastern European power plant resources within the Eastern European interconnected power system (IPS) [1].

The price of electricity in Eastern Europe is comparable low. E.g. in Russia the electricity market price amounts between 10 €/MWh in the eastern part and 15 €/MWh in the western part. In Germany the electricity price amounts 55 €/MWh and will continuously increase within the next couple of years [2].

In general it is possible to synchronously connect a couple of large generation units in Eastern Europe (i.e. Russia, Belarus or Ukraine) with the European interconnected system, the UCTE system. This paper outlines different realization steps for the eastern extension of the UCTE grid for the sake of energy import from eastern European countries at a considerable lower price level and discusses the need for additional information technology infrastructure in order to operate the entire system. While technology for interconnection is available today, the remaining question is how the market prices for electric energy will change with increasing amount interconnection capacity. After outlining and discussing the technological options for interconnections, a model for the economic evaluation of increasing the energy import from the Eastern European interconnected system will be proposed.

2. INTERCONNECTION OPTIONS

In general, the realization of new enlarged interconnected power systems by synchronous links requires numerous and extensive studies (see [3]). Concerning the general information the present state of the systems must be fully documented and reliable forecasts must be available for the future power generation and consumption of each partner utility. The installed capacity in relation to peak load must be in a balanced ratio. Each network to be interconnected must have sufficient transmission and production capacities. The technical level of the equipment in operation must be of comparable quality; otherwise time schedule and cost estimates have to be formulated to achieve this goal within a prespecified time horizon. Communication and control facilities must be adequate for comparable operating procedures. In this respect the adaptation of protective devices and time limits of protection must be guaranteed. Load frequency control concepts must be agreed upon in order to participate in an adequate manner in the reserve provision. General defense and restoration plans must be available and reviewed on a regular basis. In conclusion, the full scale synchronous interconnection of eastern European network (IPS) with the western European network (UCTE) cannot be realized to utilize cheap generation capacity in the short term.

Besides the technical problems to be solved prior to fully synchronize the eastern European interconnected power systems, economic aspects have to be considered as well. From a pure economic perspective the coupling capacity has to be chosen with respect to the benefits. A detailed model for considering the coupling capacity between the two systems will be given in chapter 3. However, for the utilization of a certain percentage of the eastern European generation capacity there are four different interconnection options (see Table 1).

Option 1 foresees a direct synchronization of subsystem of IPS to the UCTE, as partly done already today. If more than one particular power stations of the IPS has to be coupled to the UCTE some lines of the IPS will form a subsystem that operates synchronously with the UCTE system. The topology of the subsystem has to be chosen according to reliability considerations of both systems, UCTE and IPS.

Table 1: Measures for interconnection of asynchronous grids

#	***Option***	***Problem***	***Additional Equipment***
1	Direct synchronous interconnection of subsystem	SCADA / EMS interconnection, control functionality	Phasor measurement units plus processing units
2	Case 1 plus power flow controllers and reactive power compensation	Integration in power system operation and control; coordinated operation in case of multiple control objectives	Case 1 plus additional network controllers; increased amount of measurement units
3	Asynchronous interconnection with HVDC	Only problem of coordination between interconnections	HVDC interconnections
4	Case 3 plus additional network controllers according case 2 for corridor strengthening	No direct control of network controllers needed but coordination between them and asynchronous links desired	As case 2 and case 3 plus measurement units and processing units

For long distance power transmission within this subsystem additional network controller may become necessary in order to provide suitable amount of reactive power and angle control (*option 2*) FACTS devices, conventional phase shifting transformers or compensation equipment are dedicated to provide this functionality. However, for both options the aforementioned requirements on load frequency control etc. have to be fulfilled as well. Even though the effort for required network analysis appears to be less than in case of full synchronization the formed subsystem has to fulfill all requirements of the UCTE operation policy.

These problems do not exist in case of asynchronous links by the application of High Voltage Direct Current (HVDC) schemes as back-to-back arrangement at the asynchronous border (*option 3*). Since this option does not require any adjustment at load frequency control schemes etc. and corresponding in-depth system studies. Consequently, despite the investments for HVDC stations, this option appears to be suited best for short term realization with the prerequisite that the IPS system capability allows for carrying the exported energy at a suitable reliability level. In case of network constraints on the IPS side additional network controllers can be introduced to support the system as outlined in connection with option 2 (*option 4*).

All interconnection options need to have a suitable monitoring and control system, i.e. interconnection with SCADA/EMS (SCADA/Energy Management System) systems in both regions. Even in case of option 3, monitoring of IPS network conditions or dedicated paths may become decisive for the reliability of energy export to the UCTE system. Furthermore, the more network controllers are operating in parallel, the higher becomes the coordination effort in order to avoid adverse control interactions. Since the extension of existing SCADA/EMS installations to neighboring systems is very costly and time consuming, it is proposed to install a “Hyper SCADA/EMS” (HSE) utilizing data links to existing SCADA/EMS installations and additional information from phasor measurement (PMU) units installed at certain network nodes in the major transmission paths for energy export. PMU technology is well known today in connection with wide area monitoring and control applications, introduced for enhancing network security and capability but also increasing cross border trading capacity [4]-[8] (see Figure 1).

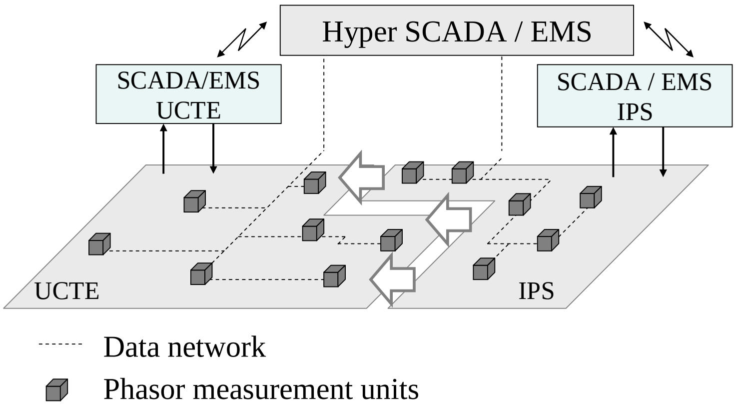

Figure 1: General structure of a Hyper SCADA / EMS system for the grid supervision of interconnected systems

A PMU measures voltages and currents at a certain node in the network at a certain point in time. A set of measurement data is tagged with a time stamp derived from a GPS signal received by the PMU. Out of at least two PMU measurement sets phasors for voltages and currents can be derived representing the RMS values and phase angles in reference to each other. For the computation an underlying network model is not needed. I.e. there is no need to establish a full scale SCADA database. The basic configuration of a PMU based wide area measurement system (WAMS) comprises of hardware:

- Phasor Measurement Units (PMU)
- Communication Links (e.g. TCP/IP)
- Central Unit (Personal Computer)

In the basic concept of a WAMS the PMUs are placed in substations to allow observation of a part of the power system under any operation conditions (network islanding, outages of lines, generators etc.). In this context a certain degree of redundancy has to be foreseen to provide sufficient results in a case of unavailability of some data (PMU outage, communication failure, etc.) [6]. Based on PMU signals basic state estimation routines can be applied to enhance the Phasor database for further analysis [9]. Basic Services create a system-wide snapshot out of the measurement. For the basic services to run properly, a minimum set of measurements must be available. Applications, which are normally initiated and are using the collected data can analyze various phenomena in power systems, such as

- frequency instability, voltage instability or overload situations,
- actual temperature conditions of the transmission paths, etc.

Based on the measured phasors, performance indicators of the power system can be derived. Those are taken as input for different control applications. Examples for performance indicators are:

- Loading of a corridor that is not fully connected to one single SCADA / EMS system
- Real conductor temperature and loading reserve
- Changes in topology in neighbored systems (forced and unforced)

Based on a general WAMS scheme the aforementioned issues in connection with option 1 to option 4 can be resolved by the introduction of a HSE layer on top of existing power automation installations. This layer is fed by two data sources: dedicated signals from existing SCADA/EMS applications and PMU signals.

In conclusion the installation of a new energy management system layer based on wide area monitoring and control technology enables the operation of different interconnection options for an increased coupling of UCTE and IPS systems without a costly and time consuming extension of existing SCADA/EMS installations in both interconnected power systems.

3. ECONOMIC EVALUATION MODEL

Independent of the interconnection options the degree of market opening is determined by the amount of traded energy. For a system with demand following offers of generation capacity the market price of one particular region can be estimated based on a merit-order curve of the energy price structure of existing generators. In this context market mechanisms like speculation are not considered in the first step. The change in energy demand in Western Europe in the context of continuously increasing prices for electricity is marginal. Furthermore it will be assumed that the merit-order curve for generation capacity, a monotonously increasing nonlinear function of the energy demand, can be simplified by a linear relationship [10], [11]. Based on these assumptions the price difference between these markets can easily expressed as a function of the exported energy.

Figure 2 shows the simplified merit-order curves of the Western (a) and Eastern (b) European markets for electricity. At a certain demand level of $P_a^{(1)}$ the corresponding market price is $K_a^{(1)}$; same applies for the market (b). In case of increasing the interconnection capacity by ΔP the price difference between the two markets will be reduced from $\Delta K^{(1)}$ to $\Delta K^{(2)}$, assuming that the demand will remain constant.

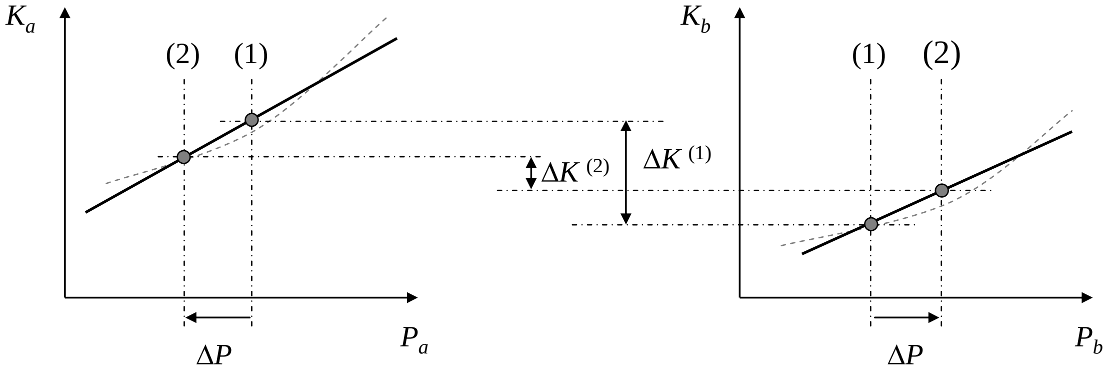

Figure 2: Merit-Order-Curves of a western (a) and an eastern (b) European energy markets, indication on changes in prices with respect to exported energy

Mathematically the price curves can be formulated by linear equations. Based on starting point (1) a certain increase in interconnection capability the prices in the two market areas will change to (2). The two state can be expressed as:

$$K_a = s_a \cdot P_a + K_{a0}\,,\; K_a^{(1)} = s_a \cdot P_a^{(1)} + K_{a0}\,,\; K_a^{(2)} = s_a \cdot \left(P_a^{(1)} - \Delta P\right) + K_{a0} \tag{1}$$

$$K_b = s_b \cdot P_b + K_{b0}\,,\; K_b^{(1)} = s_b \cdot P_b^{(1)} + K_{b0}\,,\; K_b^{(2)} = s_b \cdot \left(P_b^{(2)} + \Delta P\right) + K_{b0} \tag{2}$$

Subsequently, the change in market price difference (Eq. (3)) at a certain market opening (i.e. interconnection capacity) only depends on the slopes of the two price curves (Eq. (4)).

$$\Delta K := \Delta K^{(1)} - \Delta K^{(i)} \tag{3}$$

$$\Delta K(\Delta P) = K_0 - \left(s_a + s_b\right)\Delta P \tag{4}$$

Due to load variations the market opening determining the price difference is not a fixed value. In general ΔP has to be assumed to be variable depend on time. Since this economic model does not comprise method for the regulating power market a base load product can be assumed. The first step toward calculating the resulting revenues is to find an expression for the traded energy per time trading period ΔT (e.g. ΔT = 1a, for a front year base contract).

$$\Delta E = \Delta\overline{P} \cdot \Delta T \tag{5}$$

The resulting revenues out of this type of energy trading contract can be estimated to:

$$R_{\Delta T} \approx \left(K_0 \cdot \Delta\overline{P} - \left(s_a + s_b\right) \cdot \Delta\overline{P}^2\right) \cdot \Delta T \tag{6}$$

It is reasonable that this expression shows a certain maximum at the optimal amount of market opening, i.e. interconnection capacity; varying with the inherent market structure, represented here by the slopes of the cost functions. As a numerical example some sample market parameters have been taken to underline this behavior. Assuming a fixed price difference between the markets without opening the decisive factor for the shift of the optimum coupling capacity is the sum of the slopes of the cost functions. Figure 3 depicts a sample calculation of the expected revenues as a function of the interconnection capacity and different slopes of the price functions of the two markets.

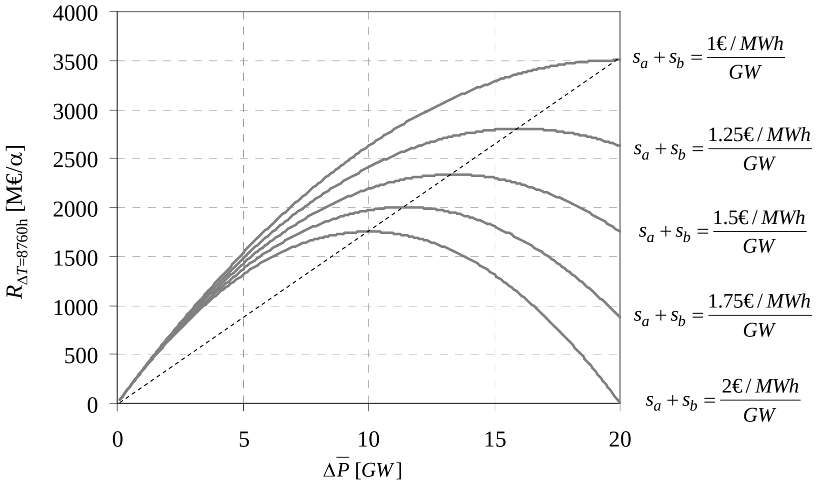

Figure 3: Estimated revenues resulting out of energy trading between Eastern and Western Europe as a function of interconnection capacity and different market characteristics

This simple analysis of the markets demonstrates that the optimum interconnection capacity varies with the same factors as the slopes for the price functions do. For an estimated change in prices of electricity in the region of Germany of about 1.5 (€/MWh)/GW and 0.5 (€/MWh)/GW in the western part of the IPS the optimum interconnection capacity turns out to be 10 GW. Half the slope means double interconnection capacity to gain the optimum but also to increase revenue by about 30% at the same amount of interconnection capacity.

As a second result it can be concluded that market characteristic does not play a major role in revenue generation up to an interconnection capacity of around 5 GW, assuming that the range of parameters represents a suitable bandwidth.

For investment considerations the profit expectations dominate the investment decisions. Therefore the costs for interconnection equipment have to be considered in relation to the market yields. In this paper the proposed economic model concludes with a simple example that underlines the importance of the evaluation of different interconnection option in terms of investment cost. Assumption of the interconnection cost are taken ob the basis of gas turbine installations as maximum cost. If an interconnection option is assumed to have lower investments, down to one fifth new generation capacity. Based on this interconnection cost are assumed in the range of 100 - 500 €/kW. Taking into account the worst case market characteristic according to Figure 3 the resulting profit per year (*P*) for the assumed depreciation period of three years is shown in Figure 4.

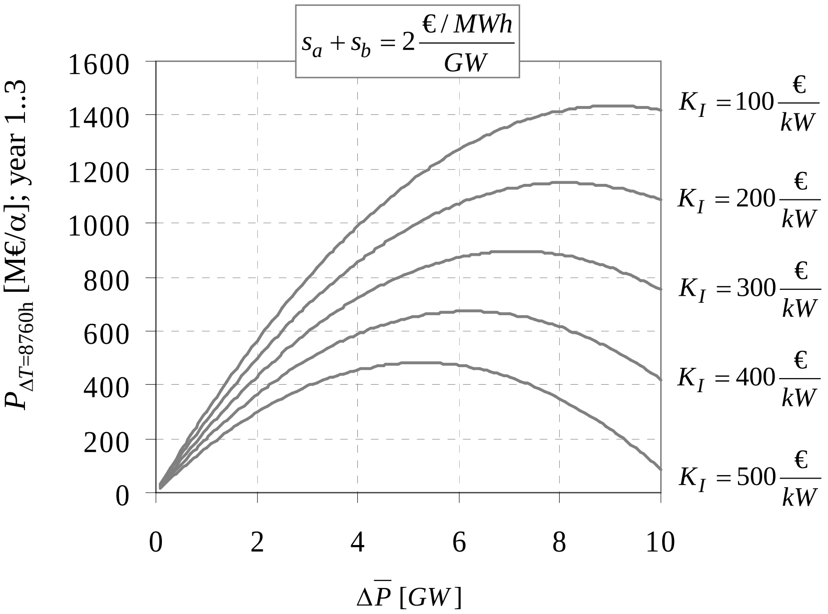

Figure 4: Yearly profit out of interconnection between Western and Eastern European electricity markets during depreciation period for interconnection investment, vs. interconnections capacity and depending on interconnections cost ; calculated for a depreciation period of three years.

In this example only static investment cost considerations have been applied. Nevertheless even for the maximum of the assumed investment cost of 500 MW/kW for coupling capacity, the optimum of market opening turns out to be 5 GW.

4. CONCULSION

Technologies for the interconnection of the Western European and Eastern European interconnected power systems for the sake of cross border trade of electricity exist today. Common to all interconnection options is the need for an information technology based framework that allows for a secure and reliable operation of the interconnections without installing complete new SCADA/EMS systems. The applications of phasor measurement units allow for partly supervision of sub-network and transmission paths and enable the operation of Hyper SCADA/EMS (HSE) system. The proposed HSE system represents an operational layer on top of existing SCADA/EMS installations and is considered to become the preferred solution for cross border electricity trade infrastructure in the above mentioned context with short term realization capabilities. For the economic evaluation of interconnection options a model based on simplified merit order curves has been introduced. It has been shown that for a small amount of additional transmission capacity for cross border trade the market price development is not strongly connected with the particular market characteristics. A numerical example showed an optimum interconnection capacity of about 5GW to 10GW for the extension of the Western European interconnected system to Eastern Europe.

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