Renewable Energy Supply for Power Dominated, Energy Intense Production Processes – A Systematic Conversion Approach for the Anodizing Process

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Abstract. European countries are highly dependent on energy imports. To lower this import dependency effectively, renewable energies will take a major role in future energy supply systems. To assist the national and inter-European efforts, extensive changes towards a renewable energy supply, especially on the company level, will be unavoidable. To conduct this conversion in the most effective way, the methodology developed in this paper can support the planning procedure. It is applied to the energy intense anodizing production process, where the electrical demand is the governing factor for the energy system layout. The differences between the classical system layout based on the current energy procurement and an approach with a detailed load-time-curve analysis, using process decomposition besides thermodynamic optimization, are discussed. The technical effects on the resulting energy systems are shown besides the resulting energy supply costs which will be determined by hourly discrete simulation.

1. Introduction

According to [1], in Germany the energy consumption in the industrial sector is about 4.2 EJ in 2011. The energy consumption per 1000 € turnover in the different industrial sectors ranges between 0.2 GJ/1000€ in the tobacco processing industry and 32.3 GJ/1000€ in the coal mining industry. The third largest energy intensity per turnover is located in the fabrication of metal products and metal processing with 8 GJ/1000€ turnover in the year 2011. Thus the developed methodology introduced in this paper is applied to the anodizing process which is an important metal processing process for aluminium products.

The German energy sector is mainly driven by conventional fuels for space-, process-heating and electricity production. Referring to [2], the import dependency in the German energy sector changed from 60.74 % in the year 2006 to 59.78 % in the year 2010. With regard to [3] the share of renewables in the energy consumption in Germany increased from 8 % to 10 % in the same period. Therefore implementation of renewable energy technologies on the national, company and household level will be the key for lowering the import dependency in the future.

2. The Classic Layout Approach

The classical layout approach, depicted in Figure 1, for retrofitting renewables in an existing energy system, is taking the “Current Process and Energy System” and the energy procurement as basis for the system layout. Due to the fact that detailed knowledge about the process itself and its internal
energy distribution is normally only existing in the process design company, not in the retrofitting company, the process is regularly regarded as black box. The energy flows in the company and the energy converter technologies are known, hence the “Supply”, quality levels and in the best case “Supply-Time Curves” for the different energy carriers are known and can be used. However in most cases Supply-Time Curves are not available and only production data is existent for modelling.

The “Local Renewable Potentials” depend strongly on the location of the investigated facility. In this study, the weather data for a test facility in Germany are used. The annual solar irradiation is 950 kWh/m². The mean wind speed in 10 m height is 4.5 m/s.

For the electrical sector, wind energy, solar irradiation, and a bio-diesel driven combined heat and power (CHP) unit are considered. Due to the fact that the demand cannot be satisfied with local wind and solar potential, the bio-diesel CHP is used for filling the gap. For the heating sector, solar irradiation and the CHP are considered. Geothermal potential is also interesting, but only for low temperature operation, which was negligible for the considered anodizing process.

In the considered case, the energy demand was supplied through a 130 °C thermal oil grid and a 230/400 V AC-network. Therefore the “Conversion Technologies” must achieve these energy quality levels. Hence technologies like near surface ground source heat pumps (GSHP), flat plate (FPC) and conventional evacuated tube collectors (ETC) could be excluded from this approach, because they are not able to supply heat on this temperature level with reasonable efficiencies [4–6]. The resulting schematic, following the aforementioned rules for the classical approach, is depicted in Figure 2.

The energy supplied to the thermal oil grid, is in this case supplied by a µ-gas-turbine CHP unit. All thermal energy is concentrated in the exhaust gas stream and can be extracted using a gas/thermal oil heat exchanger. Additionally, if the thermal demand is already satisfied and the unit runs to satisfy the electrical demand, the waste heat can be ejected through the exhaust without any further action. Thus the system has two main advantages compared to a conventional motor driven CHP unit: 1. All thermal energy concentrated in one stream with Tex>200 °C; 2. No cooling of the unit necessary.

Energy Storages are under investigation, they are mainly used to bridge gaps between demand and supply. In this study heat storage systems and electrical storages are considered. Cold storage systems are not important for the investigated process but can be implemented in further studies.

The “Control Strategy” decision in this study is taking all locally available renewable energies first. If these sources cannot satisfy the demand, the CHP unit and the storage will cover the gap.

The electricity is supplied by small wind turbines, photovoltaic cells and the CHP-unit. The heat is supplied by the CHP-unit only, because the solar thermal potential for the needed energy quality (130°C) cannot be supplied by solar thermal collectors with reasonable efficiencies under the given weather conditions.
3. The Systematic Layout Approach

The systematic layout approach, depicted in Figure 3, differs strongly from the aforementioned classical approach. In this approach the process is investigated in detail, in contrast to consider it as a black box. First of all the process is decomposed to its part processes, the minimal energy demand of each part process is determined by the laws of thermodynamic and compared to reference processes and benchmarks (I). The minimal energy flows and energy quality level, e.g. pressures, temperatures are determined (II). Internal heat recovery and other process optimizations like lowering process temperatures or introducing newer processing technologies are applied, by using thermodynamic principles like pinch-analysis (III). The load time curves are investigated with regard to load shifting and smoothing possibilities (IV). The production site is also taken into consideration, because for the retrofitting case, normally there are big potentials due to the progress in building materials over the last 20 years (V). The results of these detailed studies are the “Energy-Demand Curves” (VI) of the specific process. Blocks VII-X corresponds to Blocks described in the Classical Approach, but the valid technologies may differ with regard to the newly derived demands which will then result in a different system layout.

In Figure 4 the new structure for the systematic layout approach is depicted. The heat supply is now divided into a high temperature (100 °C) and a low temperature (60 °C) network. Therefore other energy converter technologies become valid for satisfying the demand. A heat pump and a free cooling system can be introduced. The depicted cooling load was supplied with the conventional compression chiller system with electrical energy in the conventional approach and its energy supply was integrated in the electrical load. In this approach it is used as backup only, because the process depends vital on constant temperature levels.

Figure 4 Resulting Energy Structure for the Systematic Planning Approach

The electricity is supplied by small wind turbines, photovoltaic cells and the CHP-unit. The heat is supplied by the CHP-unit and a heat pump which is also feeding the cooling load.
4. Simulation Results and Discussion

Both approaches are applied to restructure an existing energy system to a 100 % renewable supplied system, the cost structure includes operation, investment into new equipment, maintenance and fuel costs. The simulation results, depicted in Figure 5 show that the hereby introduced systematic layout approach can help, applied to the energy intense anodizing process, to reduce energy consumption up to 10 % and energy costs up to 18 % respectively. The amount of energy fed in the system by the micro wind turbine and the photovoltaic cells stay constant, due to the applied strategy of taking all locally available renewable sources first. Due to internal heat recovery with the usage of a heat pump, the energy directly fed into the heat grid by the CHP could be reduced to 45 %, relating to the conventional planning approach. Approximately 25% of the thermal energy produced by the system is supplied by internal heat recovery which also substantially lowers the electricity demand for the cooling system. The discharge energy from the electrical storage decreases, while the discharge of the thermal storage increases. Due to different cost structures this effect isn’t reflected in the cost pie charts. The amount and costs of wasted energy could be reduced by 5% using the systematic layout approach. In total, the systematic layout approach gets better result, regarding energy savings and costs, even if the higher investment costs for the heat pump are considered.

5. Conclusion

The presented systematic layout approach will significantly reduce future costs for the energy supply for producing companies. The additional expenditure of time for the planning and layout of the system, including detailed process decomposition, benchmarking and thermodynamic analysis for the planning company, will turn to account regarding the typical durability of an energy system with approximately 20 years. In this case, the systematic layout approach could have saved 2 million Euro regarding a lifespan of 20 years for the system, compared to the classical approach.

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