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Smart Energy Storages for Integration of Renewables in 100% Independent Energy Systems

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Primary energy import dependence of the European Union is currently around 53%, and it is expected that in the next 20-30 years it will reach or surpass 70%. The situation in Croatia is similar. In 2007 import dependence was 53.1%, while for 2030 it is predicted to reach 72%. Such import dependence leads to decreased security of energy supply, due to current geopolitical situation in which main sources of fossil fuels are in unstable regions and in which the competition for those resources from developing countries is growing. EU energy strategy, and a compatible Croatian strategy, is focused on policies and measures that will bring increase of share of renewable and distributed energy sources, increase in energy efficiency and energy savings and decrease in green house gas emissions. The results of previous research has shown that in order to increase efficiency and viability, there is need for energy storage, in the primary or secondary form, in order to transfer energy surplus form period of excess to the period when there is a lack. The problem of storage systems is that they increase the cost of already expensive distributed and renewable energy sources, making them, in market circumstances, even less economically viable. Although there are a number of storage technologies, as chemical, potential or heat energy, not all those technologies are optimal for each energy system. The paper shows results of energy planning and several cases where use of smart energy storage system could help with integration of the energy flows, the transformations and energy demand at the location of the energy end-use or close to it.

1. Introduction

In the EU there is strong political, public and economic support for all renewable energy technologies. Political support has been or still is reflected trough European Energy Policy and mostly through its directives as Directive 2001/77/EC for support of generation of electricity from Renewable energy sources (RES-E), new directive on the promotion of the use of energy from renewable sources 2009/28/EC; RES and Climate

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change package 20-20-20 and many other recommendations and reports. While Directive 2001/77/EC has target to meet 12% of electricity production from RES and new RES directive is setting RES target for 2020 on 20% of final energy consumption, the most recent initiatives are already started process to convert EU Energy supply to 100% RES. On 15th April 2010 RE-thinking 2050 (Zervos et al. 2010) was launched in the European Parliament under the patronage of Maria Da Graça Carvalho Member of European Parliament. The European Renewable Energy Council (EREC) outlines a pathway towards a 100% renewable energy system for the EU as the only sustainable option in economic, environmental and social terms. RE-thinking 2050 shows how the European Union can switch to a 100% renewable energy supply for electricity, heating and cooling as well as transport, and examining the effects on Europe's energy supply system and on CO_2 emissions. RE-thinking 2050 initiative will help to create Post Carbon Society for EU. A post carbon society makes possible to reframe the energy and climate change challenges as opportunities, not just to foster a wealthier society, but also a more equitable and sustainable one.
The four pillars of a Post Carbon Society (Carvalho et al., 2009):

- Renewable Energy
- Building as Positive Power Plants
- Energy Storage
- Smart grids and Plug-in Vehicles

The smart energy storage will support all four pillars of the Post Carbon Society and some of this support has been calculated by specific energy planning programs shortly described in the paper together with the analysis of case study that is presented in following chapters.

2. Methodology

In this section, the methodology of performing such analyses is described. The section introduces the reconstruction of the Croatian Energy System an energy system analysis model as well as the assumptions and regulation strategies applied to the technical energy system analyses of the increased wind power and the storage and integration technologies.

2.1 Renewable energy, its intermittency problem and energy storage

The intermittency of renewable sources like wind, solar and waves limits their use for power production as in many cases it is very hard to match intermittent production with load that is very often predictable only to certain level. Intermittency problem could be technically solved by introduction of different types of energy storages. Various energy storage options and integration of different energy and resources flows that could help solving intermittency problems in the islands energy systems, have been proposed trough Renewislands methodology (Duić et al., 2008). Intermittent nature of renewable energy sources (RES) like wind, solar and waves is one of the limitation factors for their penetration in networks especially autonomous ones. The available options for energy storage and integration of different energy and resources flows that could help solving intermittency problems in the islands energy systems, have been proposed trough Renewislands methodology (Duić et al. 2008). Case studies and calculations for pumped hydro and hydrogen are proposed in many cases (Dulć & Carvalho, 2004, Krajačić et al., 2008). Hydrogen has also been proposed as a storage means (Lund et al. 2007). Kaldellis et al. (2009) proposed storage systems for islands based on their energy systems size and shown that in those systems storage could even contribute to cost reduction of produced electricity.

As RES penetration gets higher for autonomous or weakly interconnected islands, operators give instructions for disconnection of part of RES production. Similar problems will face big power systems when RES penetration reaches certain levels. Potential use of this excess electricity can be by heat pumps and thermal energy storage proposed by (Lund 2005). The problem of storage systems is that they increase the cost of already expensive distributed and renewable energy sources, making them, in market circumstances, even less economically viable. For the case of hydrogen it has been shown in (Krajačić et al., 2009) and that price should be in range of 43 c€/kWh to 171 c€/kWh.

2.2 The energy system analyses tool

Detailed energy system analysis is performed by use of the freeware model EnergyPLAN (Aalborg University, n.d.) and H_2RES (Krajačić et al., 2009). Both models are a input/output models that performs annual analyses in steps of one hour. Inputs are demands and capacities of the technologies included as well as demand distributions, and fluctuating renewable energy distributions. A number of technologies can be included enabling the reconstruction of all elements of an energy system and allowing the analyses of integration technologies. The EnergyPLAN model is specialised in making scenarios with large amount of fluctuating renewable energy and analysing CHP systems with large interaction between the heat and electricity supply. EnergyPLAN was used to simulate a 100% renewable energy-system for the island of Mljet in Croatia (Lund et al., 2007) and the entire country of Denmark (Lund & Mathiesen, 2009). It was also used in various studies to investigate the large-scale integration of wind energy (Lund, 2005), optimal combinations of renewable energy sources (Lund, 2006), management of surplus electricity (Lund & Munster, 2003), the integration of wind power using electric vehicles (EVs) (Lund & Kempton, 2008), the potential of fuel cells and electrolysers in future energy-systems (Mathiesen & Lund, 2009), and the effect of energy storage (Blarke & Lund, 2008), compressed-air energy storage (Lund & Salgi, 2009) and thermal energy storage (Lund, 2005).

In the model is possible to use different regulation strategies putting emphasis on heat and power supply, import/export, and excess electricity production and using the different components included in the energy system analysed. Outputs are energy balances, resulting annual productions, fuel consumption, and import/exports.

2.3 The reference energy system

The Croatian energy system for 2007 has been reconstructed in the EnergyPLAN model. Energy consumption and supply data have been taken from (MINGORP, 2008) and (Vuk & Simurina, 2009) while hourly load data for Croatian power system have been provided by UCT (ENTSO-E, n.d.). Basic data about power producing units have been obtained from Croatian utility company (HEP, n.d.) and from (MINGORP, 2008). Hourly production data for hydro power plants have been reconstructed from monthly values provided in (ENTSO-E, n.d.) while hydro storage capacities have been taken from (Gereš, 2007). Load curve for hourly district heating demand was calculated according yearly consumption in Croatia (Vuk and Simurina, 2009) and according patterns of hourly heat demand in Denmark that are provided by EnergyPLAN model. Reference scenarios that are calculated by EnergyPLAN model are compared to statistical data for Croatia in order to see if they could represent situation in 2007.

3. Results of modelling in EnergyPLAN

3.1 The Energy Systems Analyses Methodology

The potential of introducing integration technologies into the reference energy system is analysed by varying the amount of renewable energy in the electricity system. In this study installed wind power generation is varied from 17MW to 7000 MW that corresponds to electricity generation from 0.04 TWh to 17.00 TWh. The total demand is 18.6 TWh of which 2.71 TWh is covered by import (nuclear).
The technical energy system analyses are conducted for a period of one year taking into consideration demands and renewable energy production during all hours.

Table 1. Results of calculation in integrating scenario.

Installed Wind (MW)	CEEP Referent. (TWh)	CEEP (TWh)	PES without RES (TWh)	RES (TWh)	CO_2 Mt
17	0	0	103.83	5.71	24.42
360	0	0	102.12	6.25	23.12
1000	0	0	99.79	7.81	22.07
2000	0.3	0	85.17	12.56	11
3000	1.6	0	81.87	14.98	10.45
4000	3.96	0.05	79.18	17.41	9.95
5000	6.22	0.41	77.56	19.84	9.55
6000	8.81	1.25	77.15	22.27	9.28
7000	11.7	2.53	77.81	24.7	9.11

CEEP referent in Table 1 represents critical electricity excess production in scenario with additional installed 1000 MW of pumped hydro storage (PHS) and 300 MW of small hydro power plants. CEEP is critical electricity excess production in the case of additional 2000 MW of PHS with 275 GWh of storage. There are also installed 40 MW of geothermal and 500 MW of PV solar and in total 120 MW of new biomass CHPs. From other storage technologies that have been used are heat pumps in combination with solar thermal collectors and 2 days heat storage in households and large heat pumps 100 MW in Group II and 500 MW in Group III and heat storage of 20 GWh each. Finally electric cars with batteries and biodiesel have been added to transport sector. RES was only not introduced in the industry sector as industry has special requirements.
The analyses are conducted with the following restrictions in order to secure the delivery of ancillary services and achieve grid stability (voltage and frequency). At least

30 per cent of the power or as a minimum 150 MW (at any hour) must come from power production units capable of supplying ancillary services, such as central PP, CHP, HPP. The distributed generation from RES and small CHP units is not capable of supplying ancillary services in order to achieve grid stability. In the analyses here, the Croatian energy system is treated as a one point system, i.e. no internal bottlenecks are assumed.

4. Conclusion

By calculations in EnergyPLAN model it was proved that it will be hard to reach total energy independence but still RES share reached 24 % in primary energy consumption and CO_2 emissions was reduced significantly. It is not the aim to recommend the precise optimal solutions for integration of RES in this paper. However, it is the aim to provide information on which technologies are fuel efficient and able to integrate RES and which approximate sizes are relevant.

Paper presents new approach in planning of Croatian energy system with significant emphasis on integration of RES energy by use of different energy storage technologies and system regulation strategies. It shows that 10 % of total electricity demand could be covered by wind energy without any significant change in current system and without

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