The Role of Concentrated Solar Power in the Internet of Energy

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Abstract. This paper discusses the role of Concentrated Solar Power (CSP) in the newly emerging concept of energy internet. The modern world demands new solutions to face climate change and CSP technology integrated into the global internet of energy network could offer new venues to these challenges. The internet of energy is an ecosystem of energy producers and energy consumers, connecting the electric grid to the internet and integrating the information and power flows bi-directionally in a common infrastructure. The main role of the Internet of Energy is to balance the grid, while CSP technology is one of the least environmentally and ecologically harmful systems, which could provide a baseload electricity generation to meet electricity demand requirements. The aim of this paper is to identify the place of CSP in the deployment of the Internet of Energy, based on a thorough literature review, an assessment of current development trends and interviews with key sector stakeholders. The discussion is also based on the experience of the DESERTEC project, as well as on the overview of newly emerged GEIDCO initiative. We analysed political, economic and technical challenges and advantages of CSP integration into the internet of energy. The results has shown that despite already proven benefits and additional value of CSP to the grid, the technology is usually overlooked by many energy scenarios of further development of electricity sector. Therefore, we argue that further work is needed in this field to ensure the integration of CSP technology in the Internet of Energy and required public support.

INTRODUCTION

Emerging information technologies such as cloud computing, Internet of Things and big data analytics, are reshaping traditional industries [1]. The energy sector also embraced the transformative technologies and integrated a digital revolution in its daily activities. The transformation of the energy sector demands new solutions of integration in the modern interconnected and globalized world. Moreover, the Paris Agreement together with the need of further integration of renewable energy urges the energy sector to adapt and find new solutions. More decentralized and decarbonized energy systems require further digitalization to manage the growing amount of data. The idea about the Internet of Energy (IoE) is not new and was actively discussed after the US and Canada blackout accident in 2003 [2], in addition to many other initiatives of intercontinental or regional integration to create a competitive and secure energy supply [3]. With the creation of China-based Global Energy Interconnection Development and Cooperation Organization (GEIDCO) in 2016 the further promotion of energy interconnection got support from 80 members coming from 14 countries.

The existing research on IoE refers to many benefits the interconnection could bring, including competitiveness, energy security and decrease in curtailment of renewables [4], [5]. Yet, despite of constantly emerging initiatives for further interconnection, many projects have failed to achieve a further energy interconnection, mainly due to obstacles related to the differences in the regulatory framework, political interests, public acceptance and etc. [5]

Despite the growing importance of the IoE, there remains a scarcity of studies regarding the role Concentrated Solar Power (CSP) will play in it. The increasing integration of intermittent energy sources, as wind and photovoltaics (PV), will require a base load source, which could balance the grid. The generation of solar thermal electricity (STE) from CSP plants is an alternative to coal, gas and large hydropower, which all have larger environmental and social impacts. The capital cost of CSP is decreasing, while the efficiency of technology is constantly improving. Many international reports envision a bright future for CSP [6], [7], giving the fact that compared with other renewables it features as a key distinction Thermal Energy Storage (TES), which enables the generation of electricity even with cloudy skies or after sunset. However, the technology still has many barriers to overcome, such as comparatively high capital cost, associated financial risks, lack of capacity building and others, which require not only technical solutions but also a new approach to the political incentives and to the current energy sector structure.

One of the biggest initiatives of interconnected cooperation projects involving the CSP system was DESERTEC. The idea was to take advantage of the high Direct Normal Irradiance (DNI) levels in the Sahara Desert and other arid regions in Southern Mediterranean countries in order to build CSP plants. The latter would provide dispatchable power to sustain local demand and also to export part of this green electricity to the European Union to supplement power plants. The electricity generated by CSP stations was going to be transmitted from MENA to Europe by High Voltage Direct Current (HVDC) overhead lines. This projects encountered many barriers and the export of energy is suspended at the moment. Yet, it has uncovered the range of possibilities for the use of CSP for the energy internet and transmission of electricity on large destination [8].

The purpose of this paper is to review recent research on the role of CSP for the grid and for intercontinental integration, based on the DESERTEC example. Moreover, the paper attempts to show the role CSP plays in the newly emerging initiatives, such as the Internet of Energy promoted by GEIDCO. Finally, we would discuss some challenges the technology might encounter in the framework of IoE. The article starts with a literature review concerning the basic concepts of the relationship between the CSP and the grid, as well as the definition of internet of energy. The second part of the article briefly discusses the obstacles of the DESERTEC projects, based on our previous research and describes the concepts underlying GEIDCO, as well as the role CSP will play in it. Finally, in the discussion we analyse the challenges CSP might face in the framework of Internet of Energy.

WHAT IS THE INTERNET OF ENERGY?

For the purpose of this paper we define the Internet of Energy (IoE) as an ecosystem of energy producers and energy consumers, which connects the electric grid to the internet and integrates the information and power flows bi-directionally in a common infrastructure. The main function of the IoE is a real time balance between the local generation and storage capability, which allows high level of consumer awareness and involvement in form of cooperation and interaction [9]. A new network which connects computers and other devices to one another is called *mesh network*, and is an alternative for the traditional top-down model of organization. It could provide greater privacy and security because traffic does not route through central organizations. Blockchain might be used for the transactions between the neighbours, which could sell directly the excess of generated energy avoiding the services of utility companies [10]. Using more smart grids, IoE will ensure reliable power supply, while data which would be generated from these smart grids could be processed using Artificial Intelligence and quantum computing [11]. Despite the fact that it seems to be futuristic, many companies already have started some pilot projects in this area, exploring the new business opportunities such interconnection brings. For instance, instead of building a big power plant to generate renewable energy, several households could be interconnected to generate large amount of electricity, as demonstrated with the project of Virtual Power Plant, developed by Tesla [12]. Moreover, Siemens together with other partners has a pilot microgrid project in Brooklyn, which enables peer-to-peer interaction. They use blockchain technology to manage complex power flows and trade energy between prosumers, increasing the resilience of the grid [10].

There is a relatively small body of literature that is concerned with the internet of energy from different perspectives. Among the problems experts highlighted are the increased energy dependency, security issues, need for further cyber protection, technical[13] and legal [14] issues which arises with possible changes of the electricity sector framework. Regarding the advantages, experts would refer to the reduction of projected energy demand with more efficient use of resources [10]; it would enable a further integration of renewables in the global electricity mix. Moreover, it increases the resiliency of the grid and reduces energy costs for final costumers.

The smaller and more isolated a power network, the more difficult it is to maintain due to nearly instantaneous balance between electricity supply and demand[3]. Therefore, a bigger network is needed to provide a stable energy supply. One of the conditions of the resilient IoE is to have a set of power plants capable to provide the electric energy required by the load and transmitted by the grid with the proper flexibility in order to face even fast load profile changes. However, in the discussions regarding the Internet of Energy experts would rather focus on wind and PV technologies, often overlooking the remaining need of baseload production. Among the available sources of dispatchable generation, the CSP technology has the least social and environmental impact, which often is neglected in the energy planning. Moreover, it provides a variety of advantages to the grid.

HOW CSP TECHNOLOGY COULD BENEFIT THE GRID?

CSP plant generates solar thermal electricity using mirrors to concentrate sun rays and produce heat for electricity generation via a conventional thermodynamic cycle. The main advantages are less intermittency because of the system's thermal inertia and the possibility to integrate the Thermal Energy Storage (TES), which enables the generation of electricity from the sun even after the sunset. Thus, it could compete with gas power plants or any similar low pollution dispatchable energy technologies, to serve as a base load in the power grid system. Data from several studies suggest the following three main advantages CSP technology could add to the grid:

- **Dispatchable renewable energy source**. With higher penetration of the renewables, the grid needs a dispatchable source to operate properly and CSP with TES could provide renewable energy on demand with low marginal cost [15]. Comparing with inflexible coal generation it could support additional generation of intermittent renewable energy source, thus reducing the curtailment. Therefore, TES allows the shift of the solar resource to periods of reduced solar output with relatively high efficiency[16]. NREL compared potential value to provide firm capacity between PV and CSP and demonstrated relative value of CSP is $48/MWh greater than PV in the 33% scenario[17]. Furthermore, from economic point of view the investments in CSP have already been scientifically justified in high renewable energy penetrated power systems [18]. For instance, in Gansu province with high curtailment rates and deficient system operational flexibility, the levelized overall benefit of CSP generation is about 0.238–0.300$/kWh, when replacing 5–20% VRE generation with CSP generation.
- **Supply of power at peak hours**. The thermal storage enables the power plant to supply the electricity during the peak hours when the electricity prices are higher, increasing the competitiveness and Internal Rate of Return. Project developers who invest in storage are able to increase revenues by selling at times when daily electricity prices were highest and to reduce unit costs by increasing plants' capacity factors[19]. Moreover, the CSP power plants could improve the capacity utilization of the transmission systems by having more full-load hours[20].
- **Power quality and ancillary services**. While the thermal inertia even without storage could provide less intermittence to the grid, the integrated TES provides additional benefits, such as quality power supply, ancillary services including voltage support, frequency response, regulation and spinning reserves, and ramping serves [15].

Overall, these studies indicate the importance of CSP technology with TES for the stability of the grid. With further integration of renewables, CSP technology would need to increase its share to provide power quality and ancillary services. Moreover, it has the least environmental and social impacts comparing with other baseload power plants [21]. The technical and economic viability of further interconnection, as well as the advantages described above have boosted many initiatives of intercontinental or regional integration [3]. One of the most important of these initiatives regarding CSP technology is the DESERTEC project.

INTERCONNECTION INITIATIVES: DESERTEC AND GEIDCO

The Desertec project aimed to provide at least 17% of electricity consumption in Europe by power generated in the MENA region by 2050. The project had gained quickly global attention and succeeded to gather main companies to financially support it. The Desertec Foundation was created with the purpose of advocating massive investments of up to 400 billion euros (Time Value of Money/2006) for CSP deployment in the Mediterranean region and the Desertec Industrial Initiative (DII) emerged as a consortium of energy suppliers, service providers, solar companies and financial institutions which assumed the commitment of bringing the "Desertec concept" to life. Despite technical viability and many possible advantages this project could introduce to both sides, critics were heard on both shores of Mediterranean, leading to the paralyzation of the export intention [22].

Among different challenges the project has met, an important and not well-discussed obstacle was lobby not only from conventional, but as well renewable energy sectors. Despite the fact, that theoretically, CSP technology represents a complementary source for electricity diversification, stability and security of the grid, the public subsidies for renewables are usually limited. Inside of the renewable energy sector exists a strong competition for the limited public resources and such a big and intensive investment project attracted strong opposition from the European renewable energy industry. The arguments were mainly nationalists about the advantages of value-added production in the European territory and the decentralized nature of electricity generation through photovoltaic panels and wind turbines [22].

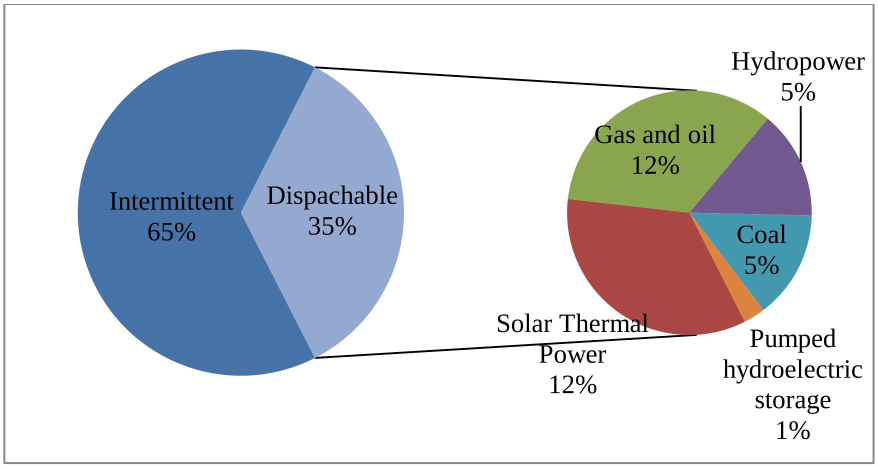
Therefore, despite detailed technical studies provided by DLR and the technical feasibility of the project, main obstacles were rather political and economic. Nowadays, this project has been relaunched in its Chinese version under the framework of Global Energy Interconnection, which promotes further integration of renewables in global energy framework, as well as the concept of Internet of Energy. In 2012 Siemens and Bosch, both founding companies of DESEREC Industrial Initiative (DII) announced their withdrawal from the project due to the risks involved in the project. While many other companies followed the example of Siemens and Bosch, Chinese State Grid Corporation decided to join the initiative in 2013. Therefore, the remaining members are the Saudi company ACWA Power, the German utility RWE and State Grid Corporation of China (hereafter State Grid) [23].

The participation of China in the Desertec project is an outcome of current foreign policy, which China undertook with the creation of unprecedented the Belt and Road Initiatives (BRI), announced by Xi Jimping the same year. The BRI is a massive plan to improve connectivity across the vast Eurasian continent, which includes many aspects among which the energy sector. It was in this context, that State Grid proposed 'Electricity Silk Road' (电力丝绸之路), part of the Global Energy Internet, involving three stages: domestic interconnection, intracontinental interconnection, and intercontinental interconnection [24]. Later in 2015, Zhenya Liu, the former President of State Grid announced the creation of Global Energy Interconnection Development and Cooperation Organization (GEIDCO)[1] aimed to replace fossil fuel with environmentally clean energy resources through further interconnection between all countries. The organization was founded with companies and institutions from the grid and telecommunication sector.

As a China-led multilateral energy cooperation platform, GEIDCO aims to build Global Energy Interconnection system and divides it mainly into two stages, the first stage being the achievement of regional interconnection in 2035 and the second stage in 2050 with the intercontinental interconnection in place. As stated in GEIDCO's brochure, the key concepts of the initiative are: "smart grid+ UHV grid+ clean energy" aimed to transit from fossil fuel toward low carbon intensive world energy system. "Nine Horizontal Nine Vertical" backbone grid of GEI will be formed based on the national main grids and cross-border interconnection.

According to the GEIDCO study, the future world electricity mix cannot only rely on the intermittent power resources, as PV or wind, but needs at least 35% of firm generating resources, as CSP, hydro, etc. As shown in Figure 1, GEIDCO dedicates a large place for CSP technology accounting for about 12% of total electricity generation to fill energy deficits between demand and intermittent resource generation.

[1] By its status Geidco is non-profit international organization among willing firms, associations, institutions and individuals.



Source: [25]

FIGURE 1. The share of intermittent and dispatchable electricity sources by 2050.

The 700 MW DEWA CSP project in Dubai have already received the support from Silk Road Fund, created by Chinese government to financially support BRI. The fund aims to "*strengthen the cooperation with other countries under Belt and Road framework, and facilitate Chinese electric power companies, as well as the expansion of their global presence*"[26]. Therefore, with further development of CSP sector in China, as well as its support from Silk Road funding and GEIDCO, the interconnection projects have more tools to succeed.

DISCUSSIONS – WHAT ARE MAIN CHALLENGES AND PERSPECTIVES?

The concept of Internet of Energy described in the beginning has still long way toward the implementation stage. Yet, we believe that it's important to already question the role CSP could play in a new electricity sector framework, especially with different initiatives emerging, such as DESERTEC and GEIDCO. While technical challenges will remain and further technological advances are needed, the main challenges in the interconnection projects are economic and political.

From **economic** perspective, further interconnection expects, firstly, considerable drops in energy prices and CSP will face even stronger competition from other energy sources. The cost reduction could be achieved by introducing more innovative technology approaches, de-risking of technology and can be driven by the increase of the total installed capacity. Likewise, experts argue that when the total installed PV capacity was similar with current CSP capacity, the LCOE were even higher than the actual price of CSP [27]. According to the study of Lilliestam e al. [28], when the world-record low bid for PV was $0.12 per kWh, in late 2011, the global PV capacity was 75 GW – 15 times higher than the current CSP capacity, indicating that the key issue holding CSP costs high is a lack of expansion and not an inherently higher technology cost. Moreover, increasing interest from China with GEIDCO initiative and Silk and Road fund, which provides low interest investment to CSP plant, could decrease the capital expenditure, as demonstrated with DEWA CSP plant [29].

Secondly, the technological advances of batteries together with the price drop will have an important impact for CSP technology. "*With interconnected network, the electric cars with batteries, while connected to the charging station will be made available to IoE, the needs of additional storage capacity could became lower and therefore CSP plants less relevant*" [27]. Indeed, the advances and price drops of batteries remain a challenge for CSP as it could offset the advantages of storage associated to CSP. However, even without the thermal storage CSP provide less intermittency to the grid due to the thermal inertia, comparing with PV plant [30]. Additionally, even if batteries will be cheaper, related environmental consequences might be increased if the batteries are not correctly disposed or recycled [31].

Third challenge, which might arise, is the increasing risk for the buyer to engage in a long-term contact with CSP. Competitive auctions have become the dominant policy instrument for CSP support, taking over from feed-in tariffs. "*Commercially, with the growth of the network, power prices may be variable and long-time contracts are harder to achieve. Why should a customer make a long time contract, if in only a few years later other power* *sources may be available, that may be even cheaper or politically less risky?*"[32] However, recent experience with a plant in Australia, which got the lowest PPA price, showed a possibility for a new business model. While PPA covers only 125 MW of Aurora's total 150 MW, the company can sell the excess of produced energy during the peak times. Such a business model helped the company to get PPA for the lowest price as 0,061 USD/kWh and might be an answer with further interconnection.

From **political** perspective, the challenges faced by the DESERTEC project, as well as the changing paradigm of involved countries are important bases to reflect on obstacles for CSP technology in the framework of IoE. As high irradiation are usually met in the developing countries, main experts from developed countries anticipate increased political and security risks.

"*Politically, such a network needs a very high amount of trust between nations and continents. Transmission lines can be quickly cut by political leaders to influence other nations or local decisions in times of political friction. Also, acts of terror are easily done to cut off electrical power from large areas*."[32] Despite of many existent researches disproving such perception with data [22], [28], it is still present in the discussion around the interconnection projects and remains to be an important challenge to be considered [33].

Another central political challenge, which has been observed as well with DESERTEC project, is the importance of lobby group. Currently in literature and discussions regarding the global grid or IoE the main attention is given to PV and wind, promoting more decentralized generation. Less information is given regarding the importance of dispatchable sources in such interconnection. Lack of attention toward the CSP role in IoE could lead toward a less share of CSP energy in the energy planning, which leads to fewer support programs.

Finally, it is interesting to note the different visions of future energy systems being decentralized or centralized around the discussed concepts. While the IoE concept often promotes more decentralized or peer-to-peer interaction, the concepts as DESERTEC and GEIDCO refer to more centralized vision of future global energy system with large scale power plants and long distance transmission lines. These ideas or visions behind the concepts are actually the key drivers for support or opposition to policies and projects[34].

CONCLUSION

The present article has discussed the role CSP might play in the Internet of Energy. With the establishment of the interconnected network, the picks from renewables could be transferred to other countries, ensuring the security of power supply and reduction of curtailment, which many countries already started to experience with higher renewable energy penetration. The current market already provides the incentives for the global interconnection, as it could reduce the energy prices, increase the number of actors in the market and contribute to the energy efficiency. Findings of the current study refer to the importance of CSP technology in the emerging concept of IoE as a dispatchable generation energy source, which provide baseload generation, could supply power at pick hours, and ensure the power quality and ancillary services.

Despite of technical feasibility of interconnection projects, large interconnection initiatives failed to succeed mainly due to political and economic reasons. The discussion is based on the experience of DESERTEC project, which helped us to understand main reasons for project's failure and to highlight some challenges CSP could face in the framework of IoE. From economic perspectives, the research indicates that CSP will be more vulnerable to the price competition from other sources. Moreover, the technological advances of batteries together with the price drop, as well as the use of E-cars as the batteries to stabilize the grid could decrease the importance of TES once the IoE is in place. Finally, the long-term contracts may become less attractive for buyers, as with further integration cheaper options for energy generation could arise. From a political perspective, the research demonstrated that there are still concerns regarding the political and terrorist attacks, as well as the fear of the increasing dependency from other countries. Despite of various researches which scientifically disproved these arguments, it remains one of the biggest obstacles for interconnection projects.

To conclude, we suppose that one of the reasons of DESERTEC's failure was that the bases of the initiative were the profit of commercial firms, and the PV prices plumping gave additional reasons for the companies to withdraw. GEIDGO by being a non-profit international organization is different from the leading forces in DESERTEC, as it is a state-backed initiative and holds a strategic vision of the project and targets long-term profit for the involved companies and institutions. Together with Silk Road Fund among other financial tools, it has a great potential for boosting further interconnection and integration of CSP technology to promote clean energy.

However, similar to our previous findings concerning the DESERTEC project [22], the GEIDCO project, by being a Chinese-led initiative, comes with the similar possibility to favour the interests of the Chinese government, its SOEs or private companies. Moreover, experts referred to the socio- environmental problems, which could arise from the construction of new transmission lines[35]. Therefore, increasing transparency in the development of IoE is needed to ensure trust as a guiding and essential part of further interconnection. This will favour as well the construction of CSP plants, which from environmental and social aspects have the least impact among the dispatchable generation technologies.

Finally, the results has shown that despite already proven benefits and additional value of CSP to the grid, the technology is usually overlooked by many scenarios of electricity sector's development, as well as in the discussions of the Internet of Energy concept. Therefore, we argue that further work is needed in this field to ensure the integration of CSP technology in the Internet of Energy and relevant interconnection projects.

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