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Research paper

A framework for selecting the location of very large photovoltaic solar power plants on a global/supergrid

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ABSTRACT

One of the important optimization applications (minimization and maximization) is the power grid systems. National electricity grids should be interconnected to develop larger regional grids (supergrids), and further integrated to build up a worldwide grid (global grid) for minimizing consumption of natural resources and maximizing economical useful life, recycling rate, and effective usage of natural resources. These supergrids and global grid concepts can only be developed through detailed and organized supportive research studies. This research study aims to find, define, identify, describe and select location selection factors of very large photovoltaic solar power plant investments on a global grid and supergrid concepts. Grey systems theory, fuzzy (Type-1 and 2) theories, Mamdani's type fuzzy rule-based system, Interpretive Structural Modelling (ISM), Impact Matrix Cross-Reference Multiplication Applied to a Classification (MICMAC) tool, and Political, Economic, Social and Technological (PEST) framework and its extensions (SLEPT, PESTEL, PESTLE, STEEPLE, STEEPLED, DESTEP, STEER) are concurrently used in this study. Eleven (11) criteria are presented for preliminary screening (i.e. C_1: global horizontal irradiation (GHI), C_2: governments supergrid integration policy, C_3: supergrid business climate and conditions, C_4: High Voltage Direct Current (HVDC) and High Voltage Alternating Current (HVAC) electrification grid infrastructure, C_5: land use, allocation and availability, C_6: geological conditions, C_7: political, war, terror & security, C_8: topographical conditions, C_9: climatic conditions, C_{10}: water availability conditions, C_{11}: natural disaster/hazard conditions), and 191 factors are presented for pre-feasibility investment stages. Findings can directly be used or taken as a basis for further analysis by researchers and practitioners.
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1. Introduction

Electricity is very vital to our modern daily life, because of its utilization in almost everything. Extending electricity to cover several regions of the World is therefore necessary, because of continuous and increasing demand that is associated with population growth (see IEA (International Energy Agency), 2014). Apart from the escalating population, research, development and innovations in new environmentally sound products (e.g. electric vehicles) have also increased electricity demand. Hence, increase in electricity supply is very necessary.

According to the International Energy Agency (IEA), the total energy demand is expected to increase by 32% between 2012 and 2035. With this, the utilization of renewable energy (RE) sources (hydropower, geothermal, wind, solar, ocean etc.) are expected to increase by 73% in the same period, while non-renewable energy sources are expected to have run out in the future (IEA (International Energy Agency), 2014; Hirsch, 2008; Jakobsson et al., 2009; Lloyd and Forest, 2010). A transition period of a 100% RE power grid adoption is thus expected in 40 to 120 years (Kuhlman, 0000; Hussain, 0000). An important RE source widely available is the Sun (solar energy). Electricity generation from solar photovoltaics (PV) technology, has remarkably increased since 1996 (Hussain, 0000); this is due to the technological breakthroughs, that brought about the declining cost associated with PV systems. Costs associated

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Table 1
Intention announced VLPVPPs until 2015.

Project title	Installed capacity (MW_p)	Country	Stage[a]	Reference
Helios	$3000 \leq P \leq 10{,}000$	Greece	IA	ProjectHELIOS (2014)
Ladakh	$P = 7500$	India	IA	Times Of India (2015)
Westlands Solar Park	$P = 2400$	USA	IA	Westlands Solar Park (2014)
Bulli Creek	$P = 2000$	Australia	IA	CleanTechnica (2015)
Ordos Solar	$P = 2000$	China	IA	GreenEnergyReporter (2014)
Kargil	$P = 1000$	India	IA	SECI (2015)
Mohammed bin Rashid Al Maktoum Solar Park	$P = 1000$	United Arab Emirates	IA	DEWA (Dubai Electricity and Water Authority) (2014)
Quaid-E-Azam Solar Park	$P = 1000$	Pakistan	IA	QASOLAR (Quaid-e-Azam Solar Power) (2014)

[a]IA = Intention Announced.

with PV systems can be further minimized through the advantage of economies of scale, via the design of very large PV power plants.

In this study, very large photovoltaic power plants (VLPVPPs) are considered as power plants having installed capacity that is equal to or above 1000 MW_p (p = peak). Operational VLPVPP is currently non-existent worldwide, although some projects are under considerations (see Table 1) (ProjectHELIOS, 2014; Westlands Solar Park, 2014; GreenEnergyReporter, 2014; DEWA (Dubai Electricity and Water Authority), 2014; QASOLAR (Quaid-e-Azam Solar Power), 2014; Times Of India, 2015; CleanTechnica, 2015; SECI, 2015).

Cumulative capacities are considered over 3000 MW_p in Europe (Greece), 12,500 MW_p in Asia (China, India, Pakistan and the United Arab Emirates), 2400 MW_p in North America (USA), and 2000 MW_p in Australia, giving a total capacity over 19,900 MW_p worldwide. It is thus very clear that VLPVPPs shall catalyze the adoption of global grid and supergrids in the near future. European Supergrid (Elliott, 2010; Friends of the Supergrid, 2012), Supergrid Concept for America (Overbye et al., 2002), DESERTEC (DESERTEC Foundation, 2013), Gobitec and Asian Super Grid (Mano et al., 2014; Seliger and Kim, 2009), and Global grid (Chatzivasileiadis et al., 2013) are some of these futuristic concepts. Hence, finding, selecting, presenting and investigating the most appropriate VLPVPPs locations will be very beneficial for governments, organizations and investors etc. in understanding the technical and financial viability of specific VLPVPP sites for global grid and supergrids. Site selection of a VLPVPP depends on location selection factors (criteria); hence, perfectly defined, identified and selected location selection factors are obligatory. In this respect, this study is focused on finding, selecting, defining and identifying the most suitable location selection factors for new VLPVPP investments (location/site specific), needed for global grid and supergrids, using a generic decision support methodology (1st generation Original Anatolian Honeybees' Investment Decision Support Methodology, Location Selection Factors Module: 1GOAHIDSM), that is under its *research, development, demonstration, deployment, and diffusion* (RD^3&D) stage (see Saracoglu, 2016b).

Main contributions and originalities of this research paper are its: (i) presentation of 11 location selection criteria for preliminary screening stage of VLPVPP investments, and the adoption of 191 location selection criteria for pre-feasibility investment stage of VLPVPP investments, (ii) presentation of majors progress in RD^3&D of 1GOAHIDSM, (iii) presentation of a very deep document collection for literature review, a well-organized impression article collection and questionnaire survey, (iv) presentation of the first application (a sort of experiment for continuous improvements during RD^3&D) type-2 Mamdani fuzzy rule based system (fuzzy inference system: FIS) based on decision makers' preferences in this subject; this is planned to evolve to an automatic selection process based on worldwide files, (v) presentation of simple factors clustering approach, (vi) presentation of complex factors clustering by Grey Interpretive Structural Modelling (ISM), Impact Matrix Cross-Reference Multiplication Applied to a Classification (MICMAC) on Political, Economic, Social and Technological (PEST) framework, and (vii) extensions (a sort of experiment for continuous improvements during RD^3&D), that is planned to evolve to an automatic clustering process.

This paper consists of five sections. The second section presents literature review. The third section presents the application of methods in 1GOAHIDSM. Location selection factors for new VLPVPPs in global grid and supergrids are explained in the fourth section. Finally, concluding remarks and further research are discussed.

Table 2
Literature review procedure.

Step	Description
1	Identify keywords for searching on scientific online database & journal websites (KT1: very large photovoltaic solar power plant investments in the supergrid and the globalgrid concepts; KT2: very large photovoltaic solar power plants in the supergrid and the globalgrid concepts; KT3: very large photovoltaic solar power plant; KT4: very large scale photovoltaic; KT5: very large-scale PV; KT6: large photovoltaic power plant; KT7: large scale photovoltaic; KT8: large scale PV; KT9: photovoltaic power plant; KT10: VLS-PV; KT11: very large scale photovoltaic systems)
2	Search selected keywords on scientific online database & journal websites and additionally on search engines (i.e. ACM Digital Library: ACMDL, ASCE Online Research Library: ASCEOR, American Society of Mechanical Engineers: ASME, Cambridge Journals Online: CJO, Directory of Open Access Journals: DOAJ, Emerald Insight: EI, International Journal of Industrial Engineering Theory, Applications and Practice: IJIETAP, Journal of Industrial Engineering and Management: JIEM, Science Direct: SD, Taylor & Francis Online/Journals: TFJ, Wiley-Blackwell/Wiley Online Library: WB, World Scientific Publishing: WSP, www.baidu.com Baidu: SE1, www.bing.com Bing: SE2, www.dogpile.com Dogpile SE3, http://msxml.excite.com Excite: SE4, www.goodsearch.com Goodsearch: SE5, www.google.com Google: SE6, www.hotbot.com Hotbot: SE7, www.lycos.com Lycos: SE8, www.naver.com Naver: SE9, www.sogou.com Sogou: SE10, www.webcrawler.com Webcrawler: SE11, www.yahoo.com Yahoo: SE12, www.yandex.com Yandex: SE13, www.newslookup.com Newslookup: SE14, www.magportal.com Magportal: SE15)
3	Investigate found documents (papers, book chapters etc.) by their title, abstract & keywords
4	Select studies for detailed investigation and review according to their relevancy to current subject & aim
5	Investigate the selected documents in detail
6	Summarize reviewed studies in detail in the current study

Note: KT: Key Term (s); SE: Search Engine (s).

2. Literature review

Previous researches were investigated as shown in Table 2. A comprehensive review was carried out on 12 well-known scientific publishers' websites. There were nine (9) specifically selected key terms (KT) (i.e. KT1 to KT9), that covered the scope of this study. Among the numerous documents available (i.e. 2047), only thirty-one documents were found to be related to this study (Fig. 1) (Adiyabat et al., 2006; Ahadi et al., 2014; Bin and Dichen, 2013; Boran et al., 2010; Brenna et al., 2012; Carrión et al., 2008;

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