An Experimental Fuzzy Expert System Based Application For The Go/No-Go Decisions To The Geospatial Investigation Studies Of The Regions Of The Very Large Concentrated Solar Power Plants In The European Supergrid Concept

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Abstract –One of the crucial activities of today's world electricity research groups is the investigation of the modeling possibility of the international grids on the concepts of the Supergrids and the Globalgrid. The European Supergrid Concept is one of the concepts in this respect. The solar power is one of the important renewable energy resource in the European Supergrid Concept. The concentrated solar power technology is one of the solar power technologies amongst the solar power technologies. The engineering, procuring, constructing and operating of the very large concentrated solar power plants in the European Supergrid Concept shall be one of the ways to escape from the consumption of fossil fuels. This paper performs an experimental one node Mamdani type fuzzy rule base evaluation approach or application for the go/no-go decisions to the geospatial investigation studies of the regions of the very large concentrated solar power plants in the European Supergrid Concept.

Keywords – Fuzzy Logic, Concentrated Solar Power, Concentrated Solar Thermal, Concentrating Solar Power, Electricity, Energy, European Supergrid, Fuzzy Expert System, Fuzzy Inference System, Fuzzy Rule Base System, Geo-spatial Investigation, Mamdani, Power, Solar, Solar Power, Sugeno, Supergrid, Very Large Concentrated Solar Power Plants.

I. INTRODUCTION

Nowadays, Europe is one of the leading regions, that has been working on the idea and ways to decrease the percentage of the usage of the fossil fuel based electricity generation systems and to increase the percentage of the usage of the renewable energy resources based electricity generation systems. One of the challenging Europe's renewable energy target is to reach the usage of 20% renewable energy sources over the whole energy resources by 2020 [1]. The European Supergrid Concept was modeled to serve to the 21st century's electricity grid system of the Europe [2]. The solar power is one of the important and major renewable energy resource on the renewable energy resources investigation pallet [3]. The concentrated solar power/concentrated solar thermal/concentrating solar power (CSP) technology is one of the solar power technologies, that can be engineered, constructed and operated in this respect [4]. Today, the CSP technology is generally divided into four families and two systems [5, 6]. These two systems are line focus and point focus systems and these four families are the parabolic trough, the linear Fresnel, the power tower, and the parabolic dish technologies (see [5, 6]) as shown in Figure 1.

Fig. 1 The CSP technology families (Source: [5, 6]).

The researchers and practitioners on this field have been working on the design of CSPs, their resource availability, their best fit locations, their location selection factors and their location selection methods for a while [7, 8, 9]. The foundations, organizations, researchers and practitioners have been investigating the possibility of the European Supergrid Concept [10]. Nonetheless, the very large concentrated solar power plant concept is a new concept and its definition is not clear and sharp yet. In this study, the very large concentrated solar power plants (VLCSPPs) are considered as the CSP stations to have the installed power of 1.000 MW or more. In the current study, a one node Mamdani type fuzzy inference system or Mamdani type fuzzy rule base evaluation approach or fuzzy expert system based model was developed and an application was performed to show how the decisions or actions could be taken for a region to go into the detailed geospatial investigation studies for the VLCSPPs in the European Supergrid Concept.

This paper has four sections. The following section is for the review of the literature. Section 3 presents the proposed system and its experimental application. The concluding remarks and further research studies are presented in Section 4.

II. LITERATURE REVIEW

A detailed literature review on the academic publication online database and journals was tried to be performed by help of some generally used and well known key terms that were very related with the subject of the current study. The previous studies and work was tried to be presented in a very
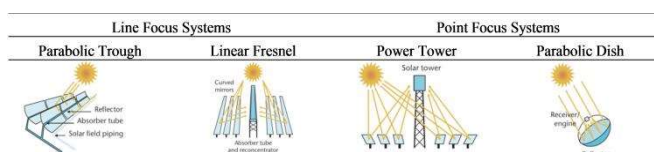
well organized and compact way in this study (see Table 1). The key terms in the current study were preferred to be as much possible as definitive, descriptive, distinctive, and specific in the search space of the online database and journals to get and obtain the most close, convenient and relevant studies on the search results for the current study.

Table 1. Literature review summary of the current study (database and journals: ACM Digital Library-ACMDL [11], ASCE Online Research Library-ASCEOR [12], American Society of Mechanical Engineers-ASME [13], Cambridge Journals Online-CJO [14], Directory of Open Access Journals-DOAJ [15], Emerald Insight-EI [16], Google Scholar-GS [17], Journal of Industrial Engineering and Management- JIEM [18], Science Direct-SD [19], Springer-S [20], Taylor & Francis Online/Journals-TFJ [21], Wiley-Blackwell/Wiley Online Library-WB [22], World Scientific Publishing-WSP [23]) .

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O to W	X	Y
ACMDL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASCEOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASME	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CJO	0	0	1*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DOAJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GS	0	0	6*	0	0	0	0	0	0	0	0	0	0	0	0	0	3
JIEM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SD	0	1*	4*	0	0	0	0	0	0	0	0	0	0	0	0	1*	1*
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TFJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Irrelevant (not relevant) document. (final date of the review: 23th September 2014)

Therefore, the key terms in the current study were queried and searched as *"European Supergrid" and "very large concentrated solar power plant" (A), "European Supergrid" and "concentrated solar power plant" (B), "European Supergrid" and "CSP plant" (C), "European Supergrid" and "FuzzME" (D), "European Supergrid" and "fuzzy multiple criteria evaluation" (E), "European Supergrid" and "fuzzy weighted average" (F), "European Supergrid" and "fuzzy OWA operator" (G), "European Supergrid" and "fuzzy ordered weighted average" (H), "European Supergrid" and "fuzzified WOWA operator" (I), "European Supergrid" and "fuzzified weighted ordered weighted average" (J), "European Supergrid" and "fuzzy Choquet integral" (K), "European Supergrid" and "fuzzy expert system" (L), "European Supergrid" and "Mamdani" (M), "European Supergrid" and " Sugeno" (N), "concentrated solar power plant" and "FuzzME" (O), "concentrated solar power plant" and "fuzzy multiple criteria evaluation" (P), "concentrated solar power plant" and "fuzzy weighted average" (Q), "concentrated solar power plant" and "fuzzy OWA operator" (R), "concen-trated solar power plant" and "fuzzy ordered weighted average" (S), "concentrated solar power plant" and "fuzzified WOWA operator" (T), "concentrated solar power plant" and "fuzzified weighted ordered weighted average" (U), "concentrated solar power plant" and "fuzzy Choquet integral" (V), "concentrated solar power plant" and "fuzzy expert system" (W), "concentrated solar power plant" and "Mamdani" (X), and finally "concentrated solar power plant" and " Sugeno" (Y),* to get a very narrowed search results' hit set with very tight links between the documents (see Table 1).

There were only 17 documents found on this review, however 14 of them were improper, inappropriate, and unsuitable documents, because each key term had been found, and seen in the different sections of the documents without any relation and joint between them and they were

not used in any manner in the same context, so that these studies could not be taken into account and accepted as the previous works. The remaining 3 studies (1 in Spanish and 2 in English) were accessible on the Science Direct. These 3 studies were in the same subject and specifically focused on the CSP plant's daily operations (focused on the design for the operational stage) and control by help of the Takagi and Sugeno fuzzy models. Morales et al. designed the supervisory control strategy of a controller at a CSP plant equipped by some cylindrical parabolic solar collectors with examining the input parameters of so-called "set-point changes", "variations in the solar radiation" and "modifications in the parameters of the inner control loop" [24]. Chauvin et al. presented a so-called "side by side Adaptive Network based Fuzzy Inference Systems" based on the Takagi-Sugeno fuzzy inference system to be able to design efficient CSP plant controller for the operational stage of these kinds of power plants [25].

This detailed and broadened literature review showed that the subject of the current study would be one of the promising subjects in the mid to long term in the research community of the VLCSPPs, the CSPPs, the European Supergrid, the fuzzy expert systems and the fuzzy based support and decision making systems. Moreover, the literature review proved that this study would be one of the first studies, that aimed to model the real world solar power applications by the fuzzy based systems, which became and added some very unique and own difficulties and challenges (no antecedents and primitive studies) by itself, because of being in the very early preparatory research view and perspective situation. The "experimental" word was specifically used in this study to describe the current study very well in a sense, that this study was a sort of the foundation of applying and investigating the instructions of an applicable, usable and preferable fuzzy based soft computing system for the CSP and the European Supergrid communities [see 26, 27].

III. THE EXPERIMENTAL PROPOSED FUZZY RULE BASE SYSTEM AND APPLICATION

The main aim of this model is to cope with, describe and deal with the ambiguous, anomalous, cloudiness, doubtful, ignorant, imprecise, incomplete, incongruent, indistinctness, nonspecific, unsharp, uncertain, unclear, unconfident and unpredictable answers, approximations, believes, definitions, data, information, reasoning, statements, and understandings of the decision makers, experts and evaluators (humankind) during the very early stages of the VLCSPPs' studies in the European Supergrid Concept to decide whether to go or to start to the detailed geospatial intelligence and investigation studies of these VLCSPPs in this multi-national and multi-continental grid or not [see for the descriptive terminology 28, 29, 30, 31, 32, 33]. The natural situations, circumstances and conditions can be described with only one very suitable, proper and useful word "fuzzy" and "fuzziness" [34]. The definition of the fuzzy on some online dictionaries are given as "difficult to perceive; indistinct or vague", "(of a person or the mind) unable to think clearly; confused" [35]; "lacking in clarity or def-inition", "being, relating to, or invoking pleasant and usually sentimental emotions" [36]. The fuzzy logic and the fuzzy set theory, that was proposed by Lotfi A. Zadeh (Lotfali Askar Zadeh, Lotfi Aliaskerzadeh) (a mathematician, electrical engineer and computer scientist,

who was born in 1921 in Baku, Azerbaijan) in 1965, can handle and deal with the fuzziness [37, 38]. Henceforth, the fuzzy logic can be used to model and solve the current problem. After a short while of the Zadeh's fuzzy logic and set theory propagated, Ebrahim H. (Abe) Mamdani presented the Mamdani fuzzy inference in 1974 based on Zadeh's fuzzy theory to be able to use Zadeh's fuzzy logic and set theory with ease on the control systems ("traditional control systems" to "fuzzy control") [39]. Afterwards, some other researchers such as Kang, Larsen, Sugeno, Takagi, Tsukamoto, proposed some other "fuzzy logic controller models", known by their names such as Sugeno, or Takagi-Sugeno-Kang (TSK) fuzzy inference system (FIS) and fuzzy logic controller (FLC) [28, 40, 41]. Henceforth, the FISs can be used for easily solving the actual cases of the current problem. In this study, the modeling is performed on the Mamdani's FIS, because of its generally accepted main advantages such as human input suitability and not having output membership functions as either linear or constant, unlike the Sugeno [42, 43, 44, 45].

When the academics, engineers, investors, and researchers ask to themselves "where to construct and operate the VLCSPPs in the European Supergrid concept", they will find out and come up with some factors, indicators, and criteria for getting the most appropriate solution. One of the studies about the measures is presented the factors in a very detailed way (e.g. Direct Normal Irradiance (DNI), High-Voltage Alternating Current (HVDC) & High-Voltage Direct Current (HVAC) electrification grid infrastructure, and political, war, terror & security conditions) [46].

The first criteria (F1) in this study is the Direct Normal Irradiance (DNI). It is defined as "Direct Normal Irradiance-synonym for beam radiation, the amount of solar radiation from the direction of the sun." [47]. Some researchers took into account this factor (effected by clouds, aerosols, water vapor, air mass, etc.) for their fuzzy models in their studies in the other subjects [48, 49, 50]. There are a lot of researches going on to estimate the DNI as accurately as possible and to visualize it as easy and understandable as possible (e.g. see Figure 2). According to these kinds of data, information, documents and models, the DNI factor was modeled in the current study.

The second criteria (F2) is the HVDC & HVAC electrification grid infrastructure. There are many issues concerning this criteria, however in this study only the distance to the grid (the distance between the investigation location and the grid) is taken into account. The losses of the generated electricity and the cost of the transmission lines are two of the important issues in the operational period of the VLCSPPs. Some researchers took into account this factor for their fuzzy models in their studies in other subjects [52, 53, 54, 55]. According to these kinds of information, documents and models, the HVDC & HVAC electrification grid infrastructure was modeled in this study.

The third criteria (F3) is the political, war, terror & security conditions. There are many issues concerning this criteria such as the political conflicts status, the war predictions, the terror risk estimations. There are some research studies and reports on these topics (for instance: reasons of wars - religion, revenge, ethnic cleansing) [56, 57, 58, 59]. Some researchers tried to forecast and model some constituent parts of this factor for their fuzzy or other types models in their studies in the other subjects [60, 61, 62].

Ghomshei et al.'s research study and paper is one of the very inspiring ones with its fuzzy models for researchers [62].
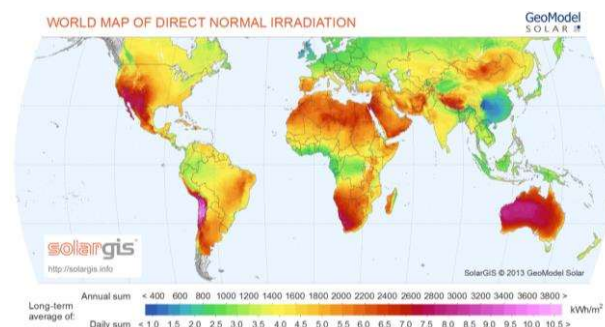

Fig. 1 World map of Direct Normal Irradiation (DNI) (Source: [51])

The mental work (modeling) of this study was performed as the paper work, the computational work was done by help of the FuzzME Software, which was developed by Holecek, Talasova, Pavlacka and Bebcakova (see [63, 64] for FuzzME). The linguistic terms, hedges and verbal scales for each factor of the model are based on the 5 Likert scales (by Rensis Likert) [65], and Zadeh's studies on the linguistic hedges [66] with considering the magical number 7, 7±2 rule for the cognitive reasons [67, 68] (5 linguistic scales) (see Table 2). All of the variables were normalized by the maximum value in the data and information set, because of performing an experimentally developed model. Totally 33 defined rules of this study were in the standard form of the Mamdani's FIS. The FuzzME screenview in this application was presented in Figure 3.

Table 2. The representative normalized membership functions on the FuzzME Software (open presentation and FuzzME model files).
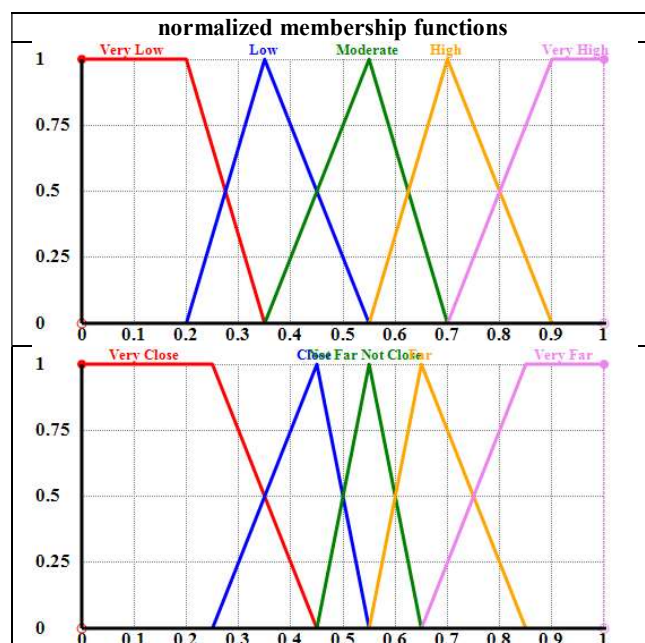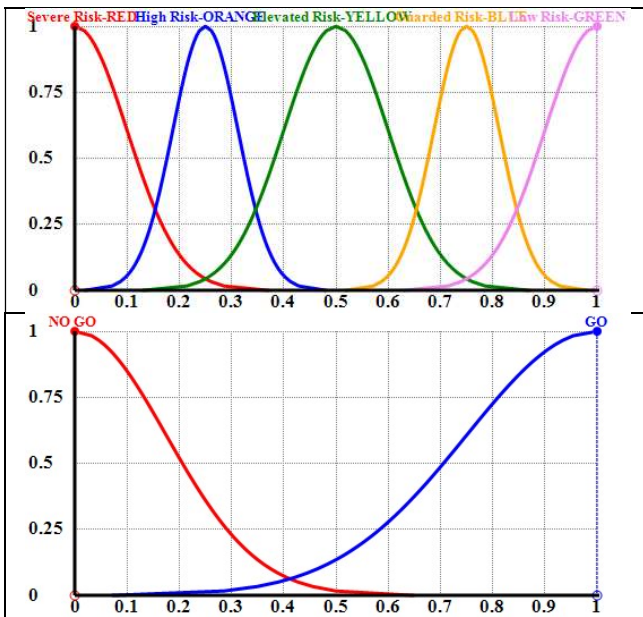
* Input: DNI F1: Increasing Scale higher values are better (1st up), HVDC & HVAC F2: Decreasing Scale lower values are better (2nd up), Political, War, Terror & Security F3: Increasing Scale higher values are better (3rd up, linguistic terms based on [69])

* Output: Increasing Scale higher values are better (down)

* Note: Increasing Scale: values in the real life are normalized with the maximum value, Decreasing Scale: first, values in the real life are normalized with the maximum value; second, normalized values are calculated and changed as x to (1-x) or directly decreasing scale selected on the FuzzME

The experimental application study was conducted for a few randomly selected regions (in the European Supergrid Concept). The capability of the FuzzME Software was very effectively used for the evaluations of the alternatives by selecting the criterion value in either simple or extended scale type (see Table 3).
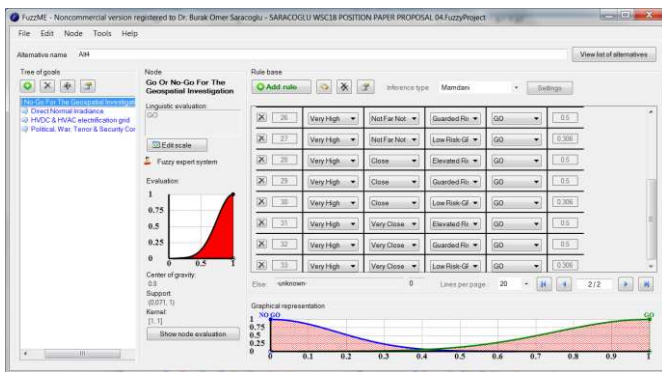

Fig. 1 The Mamdani's fuzzy rule base on FuzzME (open presentation & FuzzME files)

Table 3. The experimental alternatives on the FuzzME (open presentation and FuzzME files)

Country	Provinces & Districts*
Algeria	Adrar
	Tamanrasset
	Illizi
Morocco	Oued Ed-Dahab-Lagouira
	Laâyoune-Boujdour-Sakia El Hamra
	Guelmim-Es Semara

Table 3. The experimental alternatives on the FuzzME (open presentation and FuzzME files) (continued)

F₁	F₂	F₃
Simple	Extended	Simple
Simple	Extended	Simple
Simple	Extended	Simple
Simple	Extended	Extended
Simple	Extended	Extended
Simple	Extended	Extended

The results of the experimental application were gathered in the sorted form as GO (Alt4, Alt5, Alt6, Alt1, Alt2 and Alt3, Alt: alternative), surprisingly there were not any NO GO classified alternatives in this experimental case.

IV. CONCLUSIONS AND FUTURE WORK

It is believed that this study shows the possibility of adopting and using the Mamdani type fuzzy inference system in this specific very important and crucial subject. It is hoped that very effectively usable, and sophisticated multi mode Mamdani type fuzzy rule base evaluation models on the FuzzME will help the research and practical studies in this subject. In the future studies, all the variables about this subject should be found and identified, the fuzzification of these variables should be more detailly done, and the real world applications should be performed to help the international organizations, the multinational foundations, the governments and the investors.

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