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Review of Fuzzy Logic Applications in Performance Enhancement of Solar Based Power System.

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***Abstract*--Proper planning is required at the global, national and regional level to handle the energy consumption on one hand and consequent emissions on the other. The world has been endowed with environment friendly renewable energy sources. Academicians, policy makers and industrialists are working for developing energy models to circumvent the growing energy-environment predicament. Artificial intelligent systems namely neural network, fuzzy logic, genetic algorithm are being used for building optimization models. Energy models also help in integrated assessment considering availability, potential, economics, emission, technology, social acceptance etc. Energy projects in developing countries have proved that renewable energy can directly contribute to poverty alleviation as well as provide for business and employment opportunities. In this work we will perform a detailed survey of research advancements in the field of power sector using the solar energy by utilizing the fuzzy logic based control and estimation methodology. We have collected information about various solar system based application which are recently proposed and how the fuzzy inference system is applied in these application. Special attention will be focused on MPPT based solar system performance enhancement by use of fuzzy logic controllers. We will also describe about different latest A.I. techniques that has been hybrid with fuzzy logic for improving PV array based solar plants performance in recent time.**

Keywords*-- *PV array, Fuzzy Logic, MPPT, Renewable Energy, Solar Cell.

1. Introduction:

In every industrial sector power requirement is the backbone for its proper working and growth and it decides the financial planning up to a large extents. In recent years the cascade effects of the financial crisis have affected every sector, in varying degree and geography, the investment in renewable energy continues growing with a sustainable trend. According to the new report of the UNEP (United Nation Environment Programme), the investment in renewable energy rose 5% in 2008 proving definitely the establishment of new methods of electric power generation and confirms that this sector represents now a mainstream energy investment. The climate of the good health of renewable energy is the fruit of the interactions of the governmental and societal engagement towards tangible actions to mitigate climate change by reducing Green House Gases (GHG), reducing their dependency on fossil fuel supply and making energy security a strategic priority. Certainly, the current financial and economical crisis may have slowed down the demand on the fossil fuel energy and driven down prices. But, the world opinion is still convinced, that is only a temporary pause. It seems that there is a latent threat form energy crisis, and will constitute a good stimulus for the emergence of the renewable energy era.

To face this threat from resources depletion, solar energy is recognized as a robust alternative to unsustainable energy use in developed and developing countries. During the last two decades, the rhythm of the implementation of solar farm using PhotoVoltaic (PV) panels or Concentrated Solar Power (CSP) technologies has accelerated in the countries situated in the solar energy belt, despite their prohibitive costs. According to the International Energy Agency (IEA) solar electricity will grow up to 20-25% by 2050. The IEA has also foreseen that, by 2050, the PV and CSP systems will be able to generate 9000 TWh of electricity and reduce the yearly CO2 emissions by almost 6 billion tones [3].

Solar energy resource assessment and site suitability for large PV farms implementations is affected by different factors which can be classified in three main categories: Technical, Economical and Environmental. These factors depend on the geographical location, biophysical attributes and socio-economical infrastructure of the country under study. Notice that the dust and sand risk factors are only specific to the region and may not apply for other countries with temperate climate. The suitability of the location of a PV farm is determined based on the combination with different weights of all the factors listed above. The most insolated areas are predisposed to high suitability. Proximity to roads avoids additional cost of infrastructure construction and consequential damage to the environments. Lands that have minimal value due to past use and present conditions should be evaluated for potential PV farms deployment. PV farms are particularly suitable where the connection to the existing electric grid is effortless. The arrangement to implement PV farms in close proximity to the existing grid and loads pole reduce significantly transmission losses. Large-scale PV farms require flat terrain or fairly steep slope that is facing south with less than a 5% graded slope. The deployments of the PV at large scale were adopted in the perspective of sustainable development and mitigation of climate change, because it operates for long periods with low maintenance. PV systems were recognized as technologies that have virtually no environmental impact, because, they are clean and silent. From this standpoint, the implementation of PV farms, should respect the sensitive areas under landscape and monument protection due to aesthetic requirements. Zone of influences identified as critical risk zone for PV farms such as floods and windy area, should be avoided. Also, area with abundance of dust, combined with the occurrence of fog and mist, will affect the efficiency (revenue) of PV farms. For instance, if a solar collector surface is maintained at a cleanliness level of 90%,

the estimated annual loss in revenue reach up to 10%. Furthermore, washing with water (conventional cleaning method) may well involve prohibitive costs.

2. Literature Review:

PV is an attractive source of renewable energy for distributed urban power generation due to their relatively small size and noiseless operation. Their applications are expected to significantly increase all over the world. Solar photovoltaic power is a generic term used for electrical power that is generated from sunlight. A solar photovoltaic system converts sunlight into electricity. The fundamental building block of solar photovoltaic power is the solar cell or photovoltaic cell. solar modules are not very efficient with their ability to convert sunlight to electrical power.The efficiency can drop further due to other factors such as solar module temperature, available sunshine and load conditions. Solar module characteristics are dynamic in nature and their power generation capabilities keep on changing with the geographical location and weather conditions. In the literature, many methods have been proposed to extract maximum power from PV module. The proposed methods can be broadly classified as the perturb & observation (P&O) method, the incremental conductance (INC) method and artificial intelligence (AI) based methods. Although the P&O method is commonly used in the MPPT applications due to its simplicity and easy implementation, it has number of problems. Its accuracy in steady-state sunshine condition is low because the perturbation process would make the operating point of the PV module oscillate around the MPP, which consequently waste the energy. In recent years many artificial intelligence techniques are used like ANN, ANFIS and fuzzy logic to improvised the MPPT algorithm based PV array performance. We have analysed various works in past years which have applied fuzzy logic system and other A.I. techniques in achieving smooth and fast maximum power tracking as discussed in upcoming section.

2.1 Artificial Intelligence applications in solar power generation:

Surface incoming solar radiation is a key variable for many agricultural, meteorological and solar energy conversion related applications. In absence of the required meteorological sensors for the detection of global solar radiation it is necessary to estimate this variable. Temperature based modelling procedures was reported by Gorka Landeras et.al. in (2012), [4] in this woark a study for estimating daily incoming solar radiation by using Gene Expression Programming (GEP) was performed for the first time and analysis was also performed on other artificial intelligence models such as Artificial Neural Networks (ANNs), and Adaptive Neuro-Fuzzy Inference System (ANFIS). A comparison was also made among these techniques and traditional temperature based global solar radiation estimation equations. Root mean square error (RMSE), mean absolute error (MAE) RMSE-based skill score (SSRMSE), MAE-based skill score (SS_{MAE}) and r^2 criterion of Nash and Sutcliffe criteria were used to assess the models' performances. An ANN (a four-input multilayer perceptron with 10 neurons in the hidden layer) presented the best performance among the studied models (2.93 MJ m^{-2} d^{-1} of RMSE). The ability of GEP approach to model global solar radiation based on daily atmospheric variables was found to be satisfactory.

This work presented by S.X. Chen, H.B. Gooi, and M.Q. Wang (2013**),** [5] on the solar radiation forecast technique based on fuzzy and neural networks, which aims to achieve a good accuracy at different weather conditions. The accuracy of forecasted solar radiation will affect the power output forecast of grid-connected photovoltaic systems which is important for power system operation and planning. The future sky conditions and temperature information is obtained from National Environment Agency (NEA) and the sky and temperature information will be classified as different fuzzy sets based on fuzzy rules. By using fuzzy logic and neural network together, the forecast results can follow the real values very well under different sky and temperature conditions. The effectiveness of the approach is validated by a case study where four different scenarios are tested. The Mean Absolute Percentage Error (MAPE) is much smaller compared with that of the other solar radiation method.

Ozgur Kisi (2014), [8] investigated the ability of FG (Fuzzy Genetic) approach in modelling solar radiation of seven cities from Mediterranean region of Anatolia, Turkey. Latitude, longitude, altitude and month of the year data from the Adana, K. Maras, Mersin, Antalya, Isparta, Burdur and Antakya cities are used as inputs to the FG model to estimate one month ahead solar radiation. FG model is compared with ANNs (artificial neural networks) and ANFIS (adaptive neuro fuzzy inference system) models with respect to RMSE (Root Mean Square Errors), MAE (mean absolute errors) and determination coefficient (R2) statistics. Comparison results indicate that the FG model performs better than the ANN and ANFIS models. It is found that the FG model can be successfully used for estimating solar radiation by using latitude, longitude, altitude and month of the year information. FG model with RMSE ¼ 6.29 MJ/m2, MAE ¼ 4.69 MJ/m2 and R2 ¼ 0.905 in the test stage was found to be superior to the optimal ANN model with RMSE ¼ 7.17 MJ/m2, MAE ¼ 5.29 MJ/m2 and R2 ¼ 0.876 and ANFIS model with RMSE ¼ 6.75 MJ/m2, MAE ¼ 5.10 MJ/m2 and R2 ¼ 0.892 in estimating solar radiation.

Photovoltaic (PV) modules have nonlinear characteristics, and hence, the process of impedance matching is obligatory. Proper impedance matching ensures extraction of the maximum amount of power in a PV scheme. R. Arulmurugan, N. Suthanthiravanitha (2015) [10] also analysed that harnessing energy from abundant, free sunlight is currently in very peak at need within all the research community. The availability of inexpensive solar modules has made it possible to harvest solar energy at higher efficiency. Several algorithms that are used to operate DC to DC converters around the Maximum Power Point (MPP) are reported in the literature. Amongst those algorithms, Fuzzy Logic Control (FLC) coupled with other controllers performs well under partial shading conditions. This work designs a new 5 × 7 optimized FLC-coupled Hopfield Neural Network (NN) maximum tracking technique. A Hopfield NN is used to routinely tune the fuzzy membership function. Entire components of a PV array, a DC–DC buck-

boost zeta converter and a designed MPP tracking controller are implemented in a Matlab–Simulink tool to validate the Hopfield NN. The results validate the effectiveness and execution of the Hopfield NN using the optimized fuzzy system. The designed system was successfully tested on an experimental prototype. The experimental values demonstrate the feasibility and improved functionality of the scheme.

2.2 Fuzzy-Logic-Control-Based MPPT Algorithm:

In the work of Po-Chen Cheng, Bo-Rei Peng [13] asymmetrical Fuzzy-Logic-Control (FLC)-based Maximum Power Point Tracking (MPPT) algorithm have presented for Photo-Voltaic (PV) systems. Two Membership Function (MF) design methodologies that can improve the effectiveness of the proposed asymmetrical FLC-based MPPT methods are then proposed. The first method can quickly determine the input MF setting values via the power–voltage (P–V) curve of solar cells under standard test conditions (STC). The second method uses the particle swarm optimization (PSO) technique to optimize the input MF setting values. Because the PSO approach must target and optimize a cost function, a cost function design methodology that meets the performance requirements of practical photovoltaic generation systems (PGSs) is also proposed. According to the simulated and experimental results, the proposed asymmetrical FLC-based MPPT method has the highest fitness value, therefore, it can successfully address the tracking speed/tracking accuracy dilemma compared with the traditional perturb and observe (P&O) and symmetrical FLC-based MPPT algorithms.

Areen Abdallah Allataifeh, Khaled Bataineh, Mohammad Al-Khedher [12] have stated that solar power technologies have been efficiently developed and used increasingly in many countries that have large amount of solar radiation. Solar energy systems are considered the most attractive energy sources. Photovoltaic (PV) systems can be used as stand-alone systems and can be connected to grid. Jordan depends almost entirely on the imported oil for meeting its energy demands. Jordan has an abundance amount of solar energy where parts of Jordan get 300 days of sunshine per year. This makes the country a very promising place for solar energy utilization. The amount of power generated by a PV panel depends on solar irradiance falling on the surface, operating temperature, and load connected. A maximum power point tracker MPPT is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the battery bank or utility grid. They convert a higher voltage DC output from solar panels down to the lower voltage needed to charge batteries. The Maximum Power Point (MPP) varies upon irradiance changes, thus a maximum power point tracking is necessary to maintain the maximum power values. The efficiency of PV plant depends on inverter efficiency, maximum power point tracking algorithm, and the efficiency of PV panel. The PV efficiency depends on cell fabrication, which does not exceed 15%. Enhancing efficiency of PV panel and inverter are difficult due to technology and cost consideration. On the other hand, enhancing algorithms of maximum power point tack (MPPT) is inexpensive and can be implemented on existed PV system.

Various intelligent methods (IMs) used in tracking the maximum power point and their possible implementation into a reconfigurable field programmable gate array (FPGA) platform are presented and compared by **F.** Chekired, A. Mellit, S.A. Kalogirou, and C. Larbes (2014**).** [9] The investigated IMs are neural networks (NN), fuzzy logic (FL), genetic algorithm (GA) and hybrid systems (e.g. neuro-fuzzy or ANFIS and fuzzy logic optimized by genetic algorithm). Initially, a complete simulation of the photovoltaic system with intelligent MPP tracking controllers using MATLAB/Simulink environment is given. Secondly, the different steps to design and implement the controllers into the FPGA are presented, and the best controller is tested in real-time co-simulation using FPGA Virtex 5. Finally, a comparative study has been carried out to show the effectiveness of the developed IMs in terms of accuracy, quick response (rapidity), flexibility, power consumption and simplicity of implementation. Results confirm the good tracking efficiency and rapid response of the different IMs under variable air temperature and solar irradiance conditions; however, the FL–GA controller outperforms the other ones. Furthermore, the possibility of implementation of the designed controllers into FPGA is demonstrated.

S. L. Shimi et. Al. (2014), [7] analysed that at the present time solar energy is considered as an important source in electricity generation. Electricity from the solar energy can be generated using solar photovoltaic (PV) modules. The maximization of solar power extracted from a PV module is of special concern as its efficiency is very low. The output power of a PV module is highly dependent on the geographical location and weather conditions such as solar irradiation, shading and temperature. To obtain maximum power from PV module, photo voltaic power system usually requires maximum power point tracking (MPPT) controller. In this work, an adaptive neuro-fuzzy inference system (ANFIS) based maximum power point tracker for PV module has been presented. To extract maximum power, a DC–DC boost converter is connected between the PV module and the load. The duty cycle of DC–DC boost converter is modified with the help of the ANFIS reference model, so that maximum power is transferred to load. Due to the complexity of the tracker mechanism and non-linear nature of photo voltaic system, the artificial intelligence based technique, especially the ANFIS method, is used in this work.

G. Balasubramanian and S. Singaravelu [11] have presented a Fuzzy Logic Controller for Maximum Power Point Tracking (MPPT) in photovoltaic system. An easy and accurate method of modeling photovoltaic arrays is proposed. The model and fuzzy based control strategies are combined to form intelligent controllers that are more accurate and robust. The model based controller is designed such that the reference signal for PWM generator of the converter can be adjusted to achieve maximum power generation from the photo voltaic system. The proposed fuzzy logic controller shows better performances compared

to the P&O and PI MPPT based approach. A MATLAB based modeling and simulation scheme along with MPPT and fuzzy logic controller is proposed which are suitable for studying the *I-V* and *P-V* characteristics of a PV array under a non-uniform irradiation and different temperature. The model has been experimentally validated.

3. Conclusion:

In the past decades, both the academic and industrial communities have made great efforts to achieve performance enhancement and power efficiency improvements of PV arrays model using A.I techniques. Fuzzy logic are the most practical method found for MPPPT controller in the goal of obtaining high efficiency PV array system. The PV array performance itself has been gradually improved by incorporating various A.I. techniques like ANN, ANFIS, PCA, Fuzzy logic etc. Also, new methodologies like GA, PSO and simulated annealing based optimization techniques have appeared which may particularly improve the performance of certain parameters and alleviate the requirements of high efficiency PV array model design with regulating behaviour to maintain power generation at maximum power point. In this literature review several work has been collectively described that has been observed in recent years related to Fuzzy application in solar power generation and in the field of MPPT control methodologies using fuzzy logic and other diverse A.I. techniques that have been invented for achieving high performance PV operations.

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