Hybrid Renewable Energy Systems using Neuro-Fuzzy based DC-DC Converter

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Abstract*—Rapid depletion of fossil fuel resources necessitated research on alternative energy sources. A wind-solar hybrid system is a reliable alternative energy source because it uses solar energy combined with wind energy to create a stand-alone energy source that is both dependable and consistent. Solar power or wind power alone can fluctuate, when used together they provide a reliable source of energy. The perfect solution is to combine these two forms of energy sources to create a constant energy flow. Main objective of this paper is to study feasibility of stand-alone solar-wind hybrid power system and to maximize use of renewable energy generation system while minimizing the total system cost. However, the main drawback of PI controller is unable to adapt and approach the best performance when applied to nonlinear system. This problem can be partially overcome by utilizing the hybrid renewable Energy Systems using Single Switch DC-DC converter with fuzzy logic controller.

Index Terms: *Distributed Generation (DG), Hybrid Optimization Model for Electric Renewable (HOMER), Photo Voltaic (PV), Maximum Power Point Tracker (MPPT).*

I. INTRODUCTION

Solar energy and wind energy have been deemed clean, inexhaustible, unlimited, and environmental friendly. Such characteristics have attracted the energy sector to use renewable energy sources on a larger scale. However, all renewable energy sources have drawbacks. Wind and solar sources is dependent on unpredictable factors such as weather and climatic conditions. Due to both sources complementary nature, some of these problems can be overcome the weaknesses of one with the strengths of the other. This brings us to the hybrid solar-wind power plant concept. Hybrid energy stations have proven to be advantageous for decreasing the depletion rate of fossil fuels, as well as supplying energy to remote rural areas, without harming the environment.

Distributed Generation (DG) refers to small power plants (a few watts up to 1MW) at or near the loads, operating in a stand-alone mode or connected to a grid at the distribution or sub-transmission level, and geographically scattered throughout the service area. Distributed Generation includes small, modular technologies for electricity generation, located close to the load. DG technologies are used both in stand-alone mode as well as in grid parallel mode. Conventional electricity generating stations are typically located close to the fuel source and away from the loads, and electricity generated is conveyed through the transmission system to the load centre, which often requires large investment. Transmission and distribution costs account for about 30 per cent of the cost of delivered electricity. DG technologies obviate the need for an expensive transmission system and minimize transmission and distribution losses.

The Hybrid Optimization Model for Electric Renewables (HOMER) software is used as a tool to carry out the research. The main objective of this paper is to assess the feasibility and economic viability of utilizing hybrid Solar–Wind–battery based standalone power supply systems to meet the load requirements. The hybrid of Pico hydro, PV, wind turbine, generator and battery as back-up is the basis of assessment. The results from the simulation of renewable hybrid system shows that in order to reduce the COE, it is important to look into the amount of excess energy the system produced. COE is defined as the ratio of total annualized cost and annual load served, reducing the annualized or/and increasing the annual load served should be one of the objective of optimization.

II .WIND POWER

Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth's surface. Seasonal variations in the energy received from the sun affect the strength and direction of the wind. The wind turbine captures the winds kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture.

III. SOLAR POWER

The solar modules (photovoltaic cell) generate DC electricity whenever sunlight falls in solar cells. The solar modules should be tilted at an optimum angle for that particular location, face due south, and should not be shaded at any time of the day.

IV. HYBRID SOLAR-WIND SYSTEM

A stand-alone wind system with solar photovoltaic system is the best hybrid combination of all renewable energy systems and is suitable for most of the applications, taking care of seasonal changes. They also complement each other during lean periods, for example, additional energy production through wind during monsoon months compensate the less output generated by solar through wind during monsoon months compensate the less output generated by solar. Similarly, during winter when the wind is dull, solar photovoltaic takes over. The hybrid solar wind power system is as shown in figure 1. Applications of Solar-Wind Hybrid Power System are listed below.

1.Remote and rural village electrification
2.Ideal for cell phone recipient stations
3.Residential colonies and apartments for general lighting

With the use of renewable energy based system the emission of carbon and other harmful gases are reduced to approximately 80% to 90% in environments.

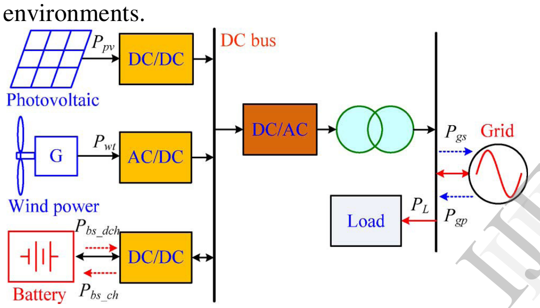

Figure 1: Solar-Wind Hybrid Power System

V. ANALYSIS METHOD

The HOMER is a micro power optimization software developed by Mistaya Engineering, Canada for the National Renewable Energy Laboratory (NREL) USA, which can useful for evaluating designs by simplifying the given task for both off-grid and grid-connected power systems for plenty of applications . It also provides the cost benefit analysis for hybrid energy system. In designing any power system, the decisions about the configuration of this system needs to be analysed, like components and its specification for the system design, size of that all components, the availability of energy resources and technological options, and the cost of each available technology, all these information are difficult to achieve.

HOMER simulations are performed by analyzing energy balance calculations and show the all possible configurations. This all possible configuration arranged by net present cost which can be useful for comparison of system design. HOMER's optimization and sensitivity analysis make this task easier. Also it finds all possible system configurations related to it.

VI. ENERGY MANAGEMENT STRATEGY OF WSB-HPS

When WSB-HPS works in stand-alone mode, if the total power generated by PV and WPG is less than the load demand, then the battery will be discharged. If the total power generated by PV and WPG is more than the load demand, the excess power will charge the battery. After the battery is fully charged, the excess power will be dumped or the PV panel and wind turbine will withdraw from MPPT state. When working in grid-connected mode, the WSB-HPS has the priority in satisfying the load demand over that provided by the utility grid. If the WSB-HPS can not produce enough power to satisfy the load demand, the shortage power will be supplied by the grid. If the total power generated by PV and WPG is more than the load demand, the surplus power has the priority in charging the battery, and then is injected into the grid.

VIII. OPTIMAL SIZING STRATEGY

The probable capacity combinations of WPG/PV/battery can be obtained. Thus, the optimal size of WPG/PV/battery will be chosen in a finite sample space.

1) Optimal Sizing Strategy in Stand-Alone Mode: The optimal sizing strategy of the proposed method is described as follows.

1) According to the output models of PV/WPG/battery and considering the battery's charge and discharge constraints the LPSP and of every probable combination can be calculated.
2) The capacity combinations of PV/WPG/ battery with better complementary characteristics can be chosen.
3) The capacity combinations with LPSP satisfying can be chosen.
4) Finally, the optimal combination of PV/WPG/battery is chosen with minimum system cost.

2) Optimal Sizing Strategy in Grid-Connected Mode: When WSB-HPS works in grid-connected mode, the battery capacity should be increased to smooth the fluctuation of power injected into the grid. In the proposed method, the concept of energy filter is applied to optimize the required battery capacity based on full utilization of the complementary characteristics of wind and solar. The energy filter is utilized to separate the low-frequency component and high-frequency component from the power injected into the grid. The impact of the low-frequency component on the grid can be ignored for its small fluctuation. The high-frequency component should be compensated by the battery for its high fluctuation. In this way, the optimal size of the battery can be obtained as shown in Figure 2.

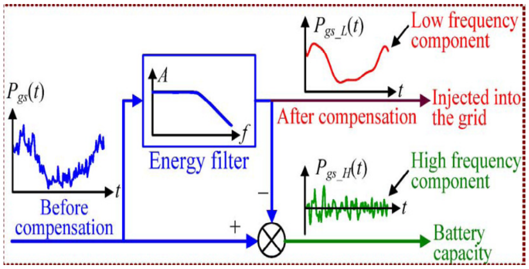

Figure 2: Optimizing the Battery Capacity Using Energy Filter.

IX. FUZZY LOGIC CONTROL

Fuzzy logic control has become an important methodology in control engineering. The contributions are divided into three parts. The first part consists of two state-of-the-art tutorials on fuzzy control and fuzzy modelling. Surveys of advanced methodologies are included in the second part. These surveys address fuzzy decision making and control, fault detection, isolation and diagnosis, complexity reduction in fuzzy systems and neuro-fuzzy methods. The third part contains application-oriented contributions from various fields such as process industry, cement and ceramics, vehicle control and traffic management, electromechanical and production systems, avionics, biotechnology and medical applications. Fuzzy logic idea is similar to the human being's feeling and inference process.

Unlike classical control strategy, which is a point-to-point control, fuzzy logic control is a range-to-point or range-to-range control. The output of a fuzzy controller is derived from fuzzifications of both inputs and outputs using the associated membership functions. A crisp input will be converted to the different members of the associated membership functions based on its value. From this point of view, the output of a fuzzy logic controller is based on its memberships of the different membership functions, which can be considered as a range of inputs.

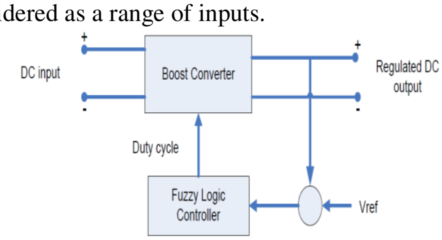

Figure 3: Boost converter with fuzzy logic controller

Computers can only understand either '0' or '1', and 'HIGH' or 'LOW'. Those data are called crisp or classic data and can be processed by all machines. To implement fuzzy logic technique to a real application requires the following three steps:

- Fuzzification – convert classical data or crisp data into fuzzy data or Membership Functions (MFs)
- Fuzzy Inference Process – combine membership functions with the control rules to derive the fuzzy output
- Defuzzification – use different methods to calculate each associated output and put them into a table: the lookup table. Pick up the output from the lookup table based on the current input during an application

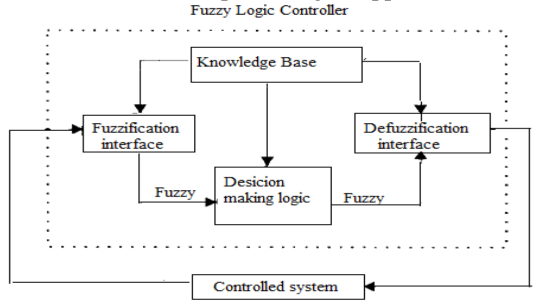

Figure 4: Structure of Fuzzy Logic Controller System

1. Fuzzification

Fuzzification is a process of making a crisp quantity fuzzy. Before this process is taken in action, the definition of the linguistic variables and terms is needed. Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into asset of linguistic terms. Next, to map the non-fuzzy input or crisp input data to fuzzy linguistic terms, membership functions is used.

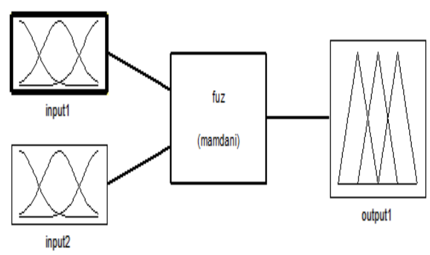

Figure 5: Membership Functions for e and ce

Note that, an important characteristic of fuzzy logic is that a numerical value does not have to be fuzzified using only one membership function meaning, a value can belong to multiple sets at the same time. There are different forms or shapes of membership functions such as Triangular, Gaussian, Trapezoidal, Generalized Bell and Sigmoidal.

2. Rule Base

In a fuzzy logic control system, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and conclusion. It can be represented by the matrix table.

Table 1: Rule Base

e \ ce	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

3. Rules of Inference

Inference is a process of obtaining new knowledge through existing knowledge. In the context of fuzzy logic control system, it can be defined as a process to obtain the final result of combination of the result of each rule in fuzzy value. There are many methods to perform fuzzy inference method and the most common two of them are Mamdani and Takagi-Sugeno-Kang method. Mamdani method was proposed by Ebrahim Mamdani as an attempt to control a steam engine and boiler in 1975. It is based on Lofti Zadeh's 1973 paper on fuzzy algorithms for complex system and decision processes. This method uses the minimum operation Rc as a fuzzy implication and the max-min operator for the composition. Suppose a rule base is given in the following form:

IF input x = A AND input y = B THEN output z = C.

After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function. It enhances the efficiency of defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of two dimensional functions. Meanwhile, Takagi-Sugeno-Kang method was introduced in 1985 and it is similar to the Mamdani method in many aspects. The first two parts of fuzzy inference processes which are fuzzifying the inputs and applying the fuzzy operator are exactly the same. But, the main difference is that the Takagi-Sugeno-Kang output membership function is either linear or constant. A typical rule in Takagi-Sugeno-Kang fuzzy model has the form as follows:

IF input 1 = x AND input 2 = y THEN output z = ax + by + c.

In my project, I used Mamdani type inference method. The input to the fuzzy controller is solar panel output voltage which is uncontrollable one and the output from fuzzy controller is controlled voltage which is maintained a constant.

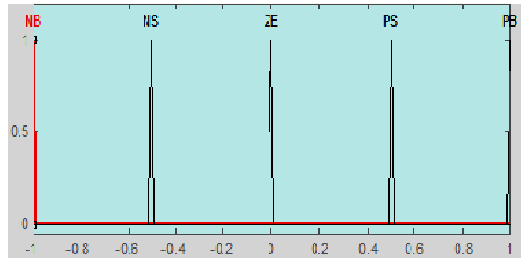

Figure 6: Output Membership Function

4. Defuzzification

After the inference step, the overall result is a fuzzy value. This result should be defuzzified to obtain a final crisp output. This is the purpose of the defuzzification component of a fuzzy logic controller system. Defuzzification is performed according to the membership function of the output variable. There are many different methods for defuzzification such as Centroid of Gravity (COG), Mean of Maximum (MOM), Weighted Average, Bisector of Area (BOA), First of Maxima and Last of Maxima. There is no systematic procedure for choosing a good defuzzification strategy, but the selection of defuzzification procedure is depends on the properties of the application. Centroid of Gravity (COG) is the most frequent used and the most prevalent and physically appealing of all defuzzification methods.

IX. SIMULATION RESULTS AND CONCLUSION

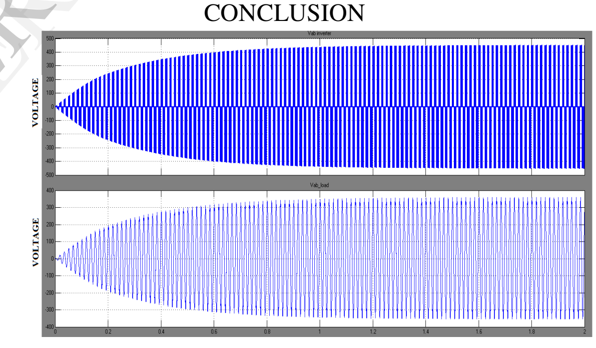

Figure 7: Three Phase Inverter Output Voltage and Load Voltage

The simulation result allows only feasible solution with their increasing in number of cost and eliminates all other infeasible possible solutions. Also simulation performs the number of parameters displayed against sensitivity variables to identify optimal solution for energy system. According to the optimal solution the total energy required to satisfy the load demand by the hybrid combination of 36% PV, 64%wind with excess electricity of 35%.

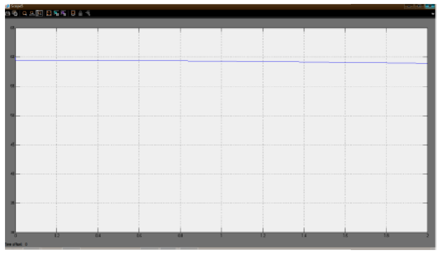

Figure 8: Converter Constant Output Voltage

Figure 9 shows monthly average electric production from wind energy and solar energy in graph format. Yellow colour indicates electric energy production from solar energy and green colour indicates electric energy production from wind energy.

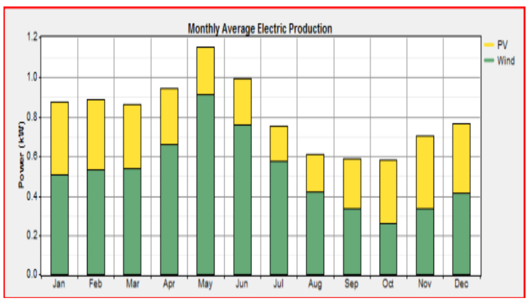

Figure 9: Graphical Representation of Result for Hybrid Solar-Wind Power System

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