FUZZY LOGIC CONTROLLER (FLC)
BASED MULTI OBJECTIVE
OPTIMIZATION OF MICRO GRID IN
BOTH AUTONOMOUS AND GRID
CONNECTED MODE

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Abstract

In this paper, the multi objective optimization of micro grid comprising of Solar, Wind turbine, Fuel Cell and Battery storage have been done using Fuzzy Logic Controller (FLC). The main objective of the micro grid is to meet the load demand satisfying the constraints in both islanded and grid connected mode with constant voltage and frequency. The optimization function have been formulated as minimization of settling time, rise time, ITAE (Integral of Time Weighted Absolute Error), ITSE (Integral of Time squared Error) and execution time. The Distribution Generators are modelled with the boost converters for meeting out the load demand and also to be connected to the utility grid. The test micro grid system has been formed in MATLAB/SIMULINK and the simulation has been carried out considering all modes of
operation. The Fuzzy Logic Controller has been proposed for the inverter operation and the rules have been framed for maintaining constant voltage at DC bus. The results prove that the proposed FLC has efficient operation in minimization of the parameters of the objective function compared with Proportional Integral (PI) Controller. Moreover, the voltages at loads and at DC bus are maintained at constant level.

**Keywords:** Micro Grid, Distributed Generation, Multi objective optimization, PI controller, Fuzzy Logic Controller

1 INTRODUCTION

In recent days, micro grid is extensively used in the distribution systems because of the naturally available sources such as solar, wind, biomass etc. Micro grids are generally defined as the combination of the various distributed energy sources, energy storage devices located nearer to the consumer end or loads. The distributed generation (DG’s) sources have wide range of applications in the power sector. Some advantages of DG’s are the relief in transmission capacity, distribution capacity, efficient utilization of the grid assets, increase in reliability, load management etc. [1]. The solar generation is reliable, easily available in most of the period, less maintenance and operation cost which leads the private sectors to invest money on solar power. The wind energy is also available in abundant in nature, but it has high installation and maintenance cost. The efficiency of wind turbine is high compared to solar output. In most of the micro grid structure, the solar and wind are popularly used.

When the micro grid is formed and connected to load, the coordination among the sources with the battery is needed for the energy management point of view. The authors [2] have presented the multi objective optimization based on PSO algorithm by optimally utilizing the renewable sources. A fuzzy controller has been framed for maintaining the desired State of Charge (SoC). The results with PSO controller is proved as better compared with PI controller with and without power exchange analysis. Adoptive Probabilistic Concept of Coincidence Interval (APCCI) has been
proposed in [3] for solving the optimization problem of cost and emission reduction. The ANN is used for forecasting and wavelet decomposition is used to increase the forecasting accuracy. The results prove that EDNSGA II is more efficient the other method.

The authors [4] have analyzed the energy management of the Micro grid using non-dominated sorting Genetic Algorithm (NSGA-II) and MOPSO methods. The cost and emission are the objective functions and the results are efficient in MOPSO compared to NSGA algorithm. In [5], an intelligent control strategy has been proposed for the grid connected micro grid system with a centralized power supervisor to monitor the local controllers. Each DG and BESS have separate controller for its operation.

The generation planning of Micro grid in grid connected mode has considered in [6] for maximum lifecycle net profit. The various methods PSO, AFS, GA, ABC and Interior point algorithm have been used to compare the results. In this paper, the modelling of the components is presented in section II. Multi Objective optimization problem formation has been presented in Section III. In the section IV, the simulation details and the results are explained. Section V presents the conclusion.

2 MICRO GRID STRUCTURE

The sources in the hybrid micro grid have been modelled in dynamic condition. The micro grid structure is shown in Figure 1. The micro grid has the distributed generation sources of solar cell, wind, Fuel cell and batteries. The voltage output from the each component is boosted up to the required level of 220V DC. The wind turbine output of AC voltage from PMSG is converter into DC voltage using the AC-DC converter. The bidirectional converter has been employed for the battery operation in order to charge and discharge the battery voltage. The SoC (State of Charge) of the battery level is maintained with in the level. The DC voltage is converted into AC voltage by suitable Inverter. After filtering out the harmonics, the voltage is supplied to the loads. Due to the intermittent nature of the renewable sources, the voltage may not be sufficient to satisfy the loads. The need of controller in the Micro grid operation is
mandatory to sense the power output from the sources and the loads and the controller should have the ability to switch over the micro grid from autonomous mode to grid connected mode. For synchronization of the micro grid with the grid, the voltage and frequency has to be maintained constant. When the PCC (Point of Common Coupling) is closed, the voltage level is boosted up using step up transformer and connected to the utility grid. The Micro grid structure is shown in Fig.1.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{micro_grid_structure.png}
\caption{Structure of Micro Grid}
\end{figure}

\subsection*{A. Solar Cell Model}

The solar cell is considered as the constant current source connected in parallel with the diode and a resistance $R_p$, series resistance $R_s$. The equivalent circuit of a single solar cell is shown in Fig. 2. The solar cells are connected in series parallel combination to form an array (low and medium power), a module (High power applications) based on the power requirement. The light falling on the solar cells is converted into electrical energy based on Photo electric effect. The $N_p$ number of cells is connected in parallel to increase the current output and $N_s$ cells are in series to increase the voltage level. The solar voltage is boosted up to the required level using internal fuzzy controller in MPPT (Maximum Power Point Tracking) algorithm. Solar of 1kW is used for the micro grid.
B. Wind turbine

The wind turbine is connected to the PMSG for the power generation. The AC voltage from the PMSG is given to the AC-DC converter which is then connected to the DC-DC boost converter. In this source also, fuzzy MPPT have been implemented for maximizing the power output. The field weakening mechanism is used before the fuzzy controller for the efficient operation of permanent magnet synchronous machines. Power rating of the wind turbine is 3.5kW.

C. Fuel Cell

The fuel cell has the ability to convert the chemical energy into electrical energy. There are many types of Fuel cell models available in the MATLAB. Based on the application, one can choose the particular cell. In this micro grid system, Alkaline Fuel Cell (AFC) is adopted due to its low cost and modeling. The reactions happened at anode and cathode of the fuel cell is responsible for the energy conversion. The Fuel cell is considered to be the source for meeting out the base load. The output voltage of fuel cell is increased by DC-DC boost converter and connected to the DC bus. Since the fuel is going to meet out the base load, the power rating of 15kW fuel cell is deployed here.
D. Battery

The energy storage element is required to save the power when we have excess energy from the renewable sources and it has to meet the load when there is shortage of power from the connected sources. In this work, battery is connected to DC bus via bidirectional converter. The State of Charge (SoC) is considered as 40% and it is maintained within the limits. Battery with 600W is chosen for the operation.

3 MULTI OBJECTIVE OPTIMIZATION PROBLEM

The objective function for the optimization problem is stated as follows:

\[
\text{Minimize } F(x) = \begin{cases} 
  t_s \\
  t_e \\
  \text{ITAE} 
\end{cases}
\]

subject to

\[
P_{DG_{min}}(t) \leq P_{DG}(t) \leq P_{DG_{max}}(t), \quad P_{b_{min}}(t) \leq P_{b}(t) \leq P_{b_{max}}(t), \quad P_{UG_{min}}(t) \leq P_{UG}(t) \leq P_{UG_{max}}(t)
\]

\[
\sum P_{DG} * S + P_{UG} * S = \sum P_{load} + P_b * S
\]

where \( t_s \) is the settling time, \( t_e \) is the execution time, ITAE is the Integral of Time Weighted Absolute Error, DG is the Distributed Generation Source, b is battery, UG is the Utility Grid, S is the switch (0 for OFF, 1 for ON).

4 SIMULATION STUDIES

Based on the power generated from DG’s, various modes of operation are considered in the analysis. **Mode 1:** The fuel cell, battery are connected to the system. **Mode 2:** In this mode, the fuel cell, Solar and the battery is connected for satisfying the load. The excess energy has been used to charge the battery. **Mode 3:** In addition to the above, wind is added at this mode. **Mode 4:**
Fuel cell, wind and battery is in operation. **Mode 5:** When all the DGs are considered in the system, but having insufficient power to meet out the load, the utility grid come into operation.

The simulation time is chosen as 2s. The timing for the connection of various sources is shown in Fig 3.

![Mode of operation](image1)

**Fig 3. Mode of operation**

![Load pattern](image2)

**Fig 4. Load pattern**

The load pattern is shown in Fig 4. The Fuzzy logic controller has been introduced for the inverter operation. The DC link voltage
error and change in error is the given as the inputs to the controller. The \text{Idref} has been obtained from the controller which is used to generate the pulses for the inverter operation. In the droop control loop, the voltage and current at PCC has been converted into dq axis frame. The real, reactive power has been calculated using the dq values. After passing through the filters, the magnitude of real power, reactive power and the voltage has been compared with the reference values. The errors are passed through the PI controllers to generate the required voltage magnitude and phase angle for the inverter operation.

The Fig 5a 5b shows the voltage at DC bus and at the loads using FLC. The DC bus voltage is maintained at constant value of 220 irrespective of the sources. The FLC have the ability to maintain the voltage and frequency even the micro grid is connected to the utility grid from 1.4s to 2s of simulation.

![Fig 5a. Voltage at DC bus](image-url)
The table I gives the comparative analysis of the objective function calculation for PI and Fuzzy logic controller.

<table>
<thead>
<tr>
<th>Controller</th>
<th>$T_s$ in Sec</th>
<th>$T_r$ in Sec</th>
<th>Execution time in Sec</th>
<th>S.D</th>
<th>ISTE</th>
<th>ITAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI controller</td>
<td>2.877e-4</td>
<td>128.2</td>
<td>228.314</td>
<td>19.337</td>
<td>1896</td>
<td>1522</td>
</tr>
<tr>
<td>Fuzzy Logic Controller</td>
<td>2.890e-4</td>
<td>118.8</td>
<td>209.981</td>
<td>19.223</td>
<td>970.8</td>
<td>1083</td>
</tr>
</tbody>
</table>

The Voltage at DC bus for PI and FLC is shown in Fig 6. It is inferred that both the controllers are maintaining the voltage efficiently at same level. From the table I, the objective function minimization has been effectively and efficiently done with FLC compared to PI controller.
5 CONCLUSION

In this paper, the Fuzzy Logic controller based multi objective optimization of the micro grid consisting of various DG’s, battery and the load is considered. The modeling of all the components is done in dynamic condition. For various load patterns, the combinations of sources are considered as modes. If the power from all the sources is not sufficient, the controller will connect the micro grid to utility grid for meeting the load demand. In the simulation, the grid is connected from 1.4s to 2.s. The results prove that the proposed FLC have better optimized results that the PI controller.

References


