LOAD FREQUENCY CONTROL OF MICROGRID WITH ANFIS CONTROLLER

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Abstract— **Due to increase in power demand the intervention of renewable energy sources (RES) into the existing power system network is increased. This results in distributed generation (DG) making it flexible. Microgrid facilitates the integration of renewables into the conventional system. The inertia of the system is less, since the renewable constitute less compared to the generators. Due to uncertain power output and varying load pattern power mismatch occurs. Inertia response is the result of rotation and is directly proportional to the rotor speed. If inertia constant (H) and load damping coefficient (D) decreases, the frequency deviation and the rate of frequency deviation are increased. Many controllers have been introduced to maintain the frequency within permissible limits. In this paper ANFIS (Artificial Neuro-Fuzzy Inference System) controller is introduced which combines the fuzzy set of rules and neural network. Results are simulated in MATLAB/Simulink software and shows improved performance.**

Keywords—distributed generation, damping coefficient, fuzzy, neural network, controller.

I.INTRODUCTION

The power system network being dynamic in nature, the demand continuously varies from its normal value and leads to small change in the state of the system. Changes in real power mainly affect the system frequency and changes in reactive power mainly depend on changes in voltage magnitude range and are less sensitive to changes in frequency. Thus real power and reactive power can be controlled separately. The Automatic Load Frequency Control (ALFC) controls the real power and the Automatic Voltage Regulator (AVR) regulates the reactive power. ALFC is not a single loop[4]. A fast primary loop responds to the frequency changes and regulates the steam flow via the speed governor and control valves to match the active power output with that of load. A slower secondary loop maintains fine frequency adjustment to maintain proper active power exchange with other interconnected network via tie-lines. This loop does not respond to fast load changes but instead focuses on changes, which leads to frequency drifting.

Photovoltaic (PV) generation is becoming increasingly important as a renewable source. To overcome the incredible power crisis in the country, the best way is to make use of renewable energy sources such as solar and wind. It is inexhaustible and non-polluting. It has the advantages of low running and maintenance cost and also noiseless operation [1].

Frequency oscillation damping is obtained using virtual synchronous generator (VSG) technique. Virtual synchronous generators are used for providing the virtual inertia to compensate the reactive power required by the system [2]. In an islanded MG with renewable sources, load change, wind power fluctuation, and sun irradiation power disturbance as well as dynamical perturbation, such as damping coefficient and inertia constants, can significantly influence the system frequency, and hence the MG frequency control problem faces some new challenges. In response to these challenges, in [3], $H\infty$ and μ -synthesis robust control techniques are used to develop the secondary frequency control loop [5].

A robust control strategy for reducing system frequency deviation, caused by load fluctuation and renewable sources, in a smart microgrid system with attached storage is used. Frequency deviation is associated with renewable energy sources because of their inherent variability [6].

As the penetration of renewable energy sources is increasing in the AC micro-grid, the stability of the closed-loop system has raised major concern since conventional distributed interface converters (DICs) used in the AC micro-grid do not have a rotating mass, and hence low inertia. High penetration of DIC-based micro-grid may result in poor frequency and voltage response during large disturbance. In order to overcome this difficulty, the virtual synchronous generator (VSGs) was proposed recently in which the DIC mimics conventional synchronous generators (SGs) by designing proper parameters of the SG into each local droop control mechanism of the DIC [9].

In paper [7] the parameters are controlled virtually using virtual synchronous generator through primary and secondary loops, and it is modified using ANFIS controller which combines neural network which modifies according to the fuzzy rules.

II. MODELLING COMPONENTS

A. SOALR SYSTEM

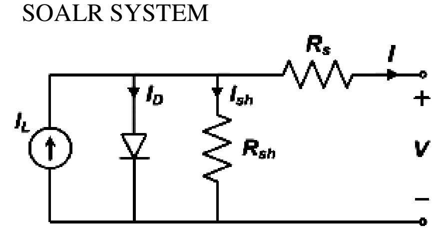

Fig1.a).Mathematical Model of Solar Cell

Modeling task is performed in MATLAB/Simulink library to create a solar array. Series and parallel connections of PV modules are prepared from solar cell blocks taken from simulink- library. Parameter specifications of solar cell are already discussed in table 1. Each module has series connection of 16 PV cells and model contains three such modules. These three strings of solar modules are connected in parallel by interconnection of same terminals (positive terminals are connected together and negative terminals are connected together). Hence there are 48 cells in series and three strings of 48 cells are connected in parallel (Ns=48 and Np = 3).

The output of solar is varying according to the irradiance and temperature hence the output of solar is given to a buck-boost converter and to connect to the grid inverter is used.

B. BUCK-BOOST CONVERTER

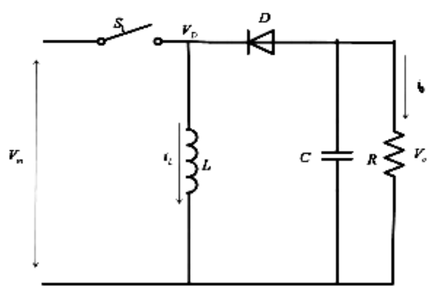

Fig.1.b).Block Diagram of Buck-Boost Converter

In fig.2 converter first transistor is turned ON and second transistor is switched OFF due to high square wave frequency. The D1 is the Schottky diode and it is turned OFF due to the positive voltage to the cathode. The inductor L is the initial source of current. If the first transistor is OFF by using the control unit then the current flow in the buck operation. The magnetic field of the inductor is collapsed and the back e.m.f is generated collapsing field turn around the polarity of the voltage across the inductor. The current flows in the diode D2, the load and the D1 diode will be turned ON. The current flows through the load and during the off period keeping Vout reasonably constant. Hence it keeps the minimum ripple amplitude and Vout closes to the value of Vs

C. INVERTER

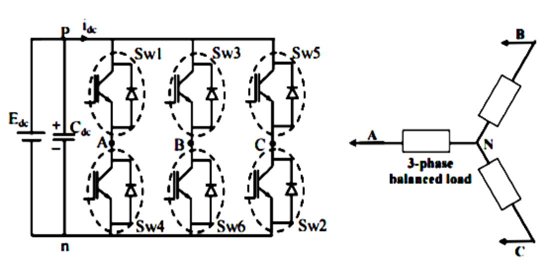

Fig.1.c).Block Diagram of Inverter

A three-phase inverter converts a DC input into a three-phase AC output. The three arms are normally delayed by an angle of 120° so as to generate a three-phase AC supply. Each inverter switch has a ratio of 50% and switching occurs after every T/6 of the time T (60° angle interval). The switches S1 and S4, the switches S2 and S5 and switches S3 and S6 complement each other. The sub-system of the entire block is created and is shown in figure.4

D. WIND ENERGY SYSTEM

Wind turbines affect the voltage level in the point of common connection (PCC) due to their power production. The active power produced by the turbine increases the voltage, whereas the reactive power can further increase the voltage level or reduce it.

The impact on the steady-state voltage level by the fixed speed wind turbine system with an induction generator directly connected to the grid is predestined and cannot be controlled during the operation. There is a capacitor bank connected at the turbine, which is typically designed to compensate for the induction machine no-load reactive power consumption. Permanent Magnet Synchronous generator is used and it is connected to the wind turbine unit. The sub-system for wind energy system is created and is shown in figure7.a

The solar and wind energy system is integrated and given to a common loading unit and a frequency sensor unit is used to measure the frequency during perturbation and is shown in figure8.

III. PROPOSED CONTROLLER

Inverter interfaced distributed generators are used as virtual synchronous generator as used in[2] to control the parameters virtually. Fine tuning is required to obtain the frequency within permissible limits. To overcome this ANFIS controller is proposed which can adapt to the changing environment depending upon the fuzzy rules.

Artificial neural network (ANN) is one of the intelligent algorithms that can be used in both identification and control. Fuzzy logic (FL) is a useful tool in control engineering, which can be used to control the variable parameters in the real-time systems. Combining FL and ANNs leads to useful and valuable results. ANNs can be trained by data, but the FL has no ability for training. ANFIS sets an adaptive modeling procedure to memorize data set information. It produces an appropriate input/output (I/O) mapping with membership functions (MFs) based on fuzzy if-then rules to generate the I/O pairs. The MFs parameters can be changed through the learning process. To adjust these parameters, the back-propagation (BP) or hybrid learning algorithm can be implemented. The ANFIS is a technique based on data processing. Therefore, to guarantee ANFIS controller performance, the I/O data must be involved the vast operational range. In this method, the fuzzy rules correction is possible when the system is being trained, and by setting the ANN appropriately, does not require any previous knowledge about the MFs and rules, and the optimum MFs are sufficient for obtaining the I/O data. The configuration of MFs depends on their parameters. The ANFIS selects these parameters automatically, and does not need a human to obtain these parameters, as a fuzzy inference system (FIS) is built by using the appropriate I/O data, which the parameters of MF are set by means of a backpropagation (BP) algorithm and the least square error (LSE).

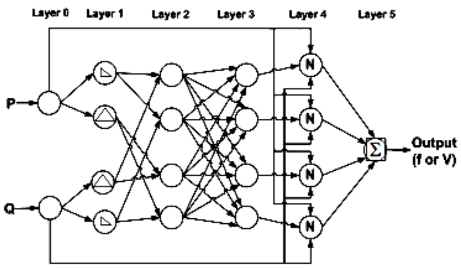

Fig.2. ANFIS STRUCTURE

In the first layer, which is known as MF layer, MFs Weights are analyzed. In this layer, the input variables are applied to obtain the fuzzy sets proportional to the inputs variables. The second layer output is the multiplication of the input signals. The input signals are equivalent to the IF parts of rules. In the third layer, which is known as rule base layer, the activity level of each rule is calculated. The number on layers is equal to the number of fuzzy rules. This layer output is a normalized form of the previous layer. The forth layer produces the output values. This layer is known as the defuzzification layer. Finally, the ANFIS output is obtained from the output layer.

To obtain an accurate model, the training data under violent changes of active and reactive loads are considered. After obtaining the training data set, the ANFIS structure to be formed. MFs of input and output are considered as linear form and Gaussian functions. After creating the control structure using the optimal hybrid method the ANFIS is trained for 5 epochs with a small error tolerance of about 0.00001ms. Total output of the system is determined using the Sugeno FIS by means of combining the output of all rules .

IV.SIMULATION RESULTS

A simulation is developed in MATLAB/SIMULINK platform to verify the effectiveness of the proposed control scheme. Buck-Boost Converter is designed as shown in figure3.a) and the input pulse and output voltage is shown in figure3.b).The inverter is operated in 120° mode of operation and the overall subsystem is shown in figure5.

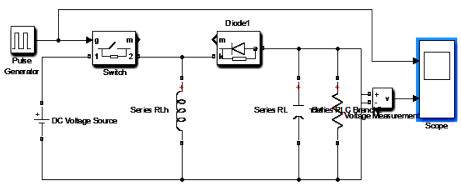

Fig.3.a).Block Diagram of Buck-Boost Converter

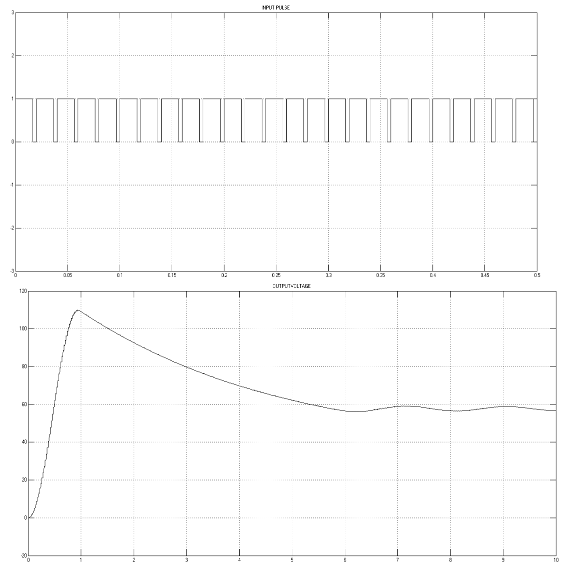

Fig.3.b).Input Pulse and output voltage of Buck-Boost Converter

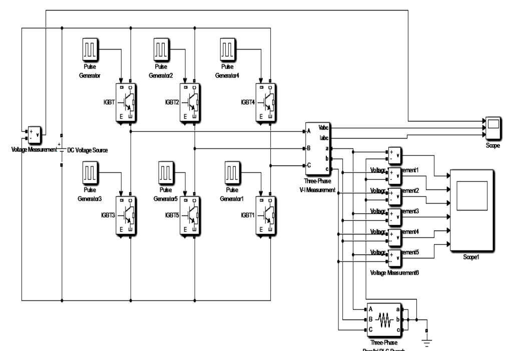

Fig.4. Inverter Model

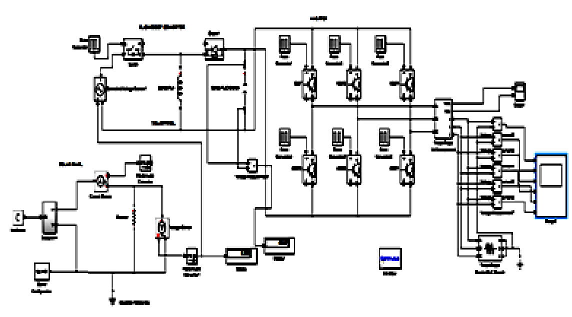

Fig.5.Solar System

Overall sub-system including the panel , converter and inverter is shown in figure5 and 6.a. Three phase output voltage is shown in figure 6.b and figure 6.c shows the output voltage and output current.

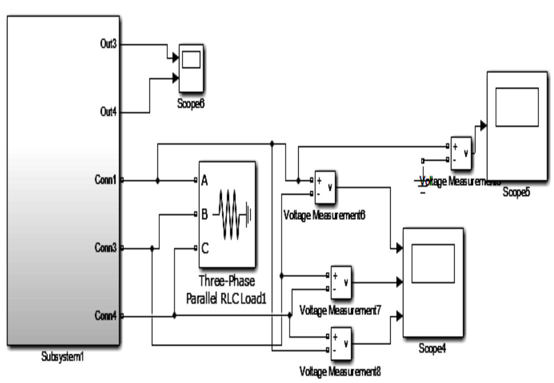

Fig.6.a).Solar Sub-system

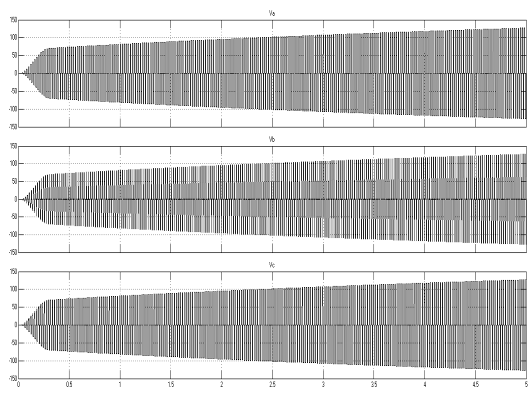

Fig.6.b).Three phase output voltage

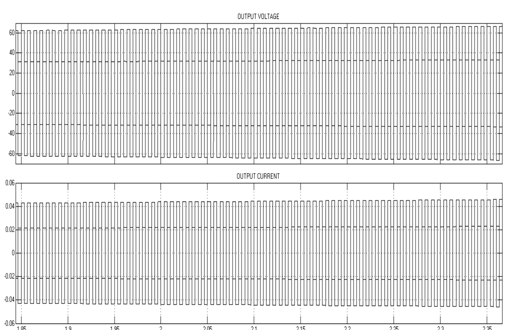

Fig.6.c) Output Voltage and output Current

In figure.8 the solar and wind system is integrated and a frequency measurement unit is used to measure the actual frequency. The frequency deviation and the derivative of the frequency deviation are given as the input to the fuzzy logic controller and is shown in figure9.a, 9.b, 9.c shows the input and output membership functions.

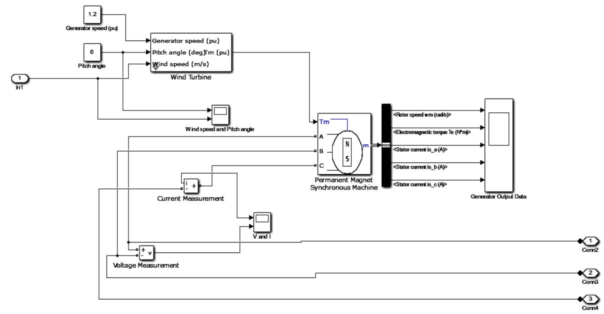

Fig.7.a).Wind Turbine Model

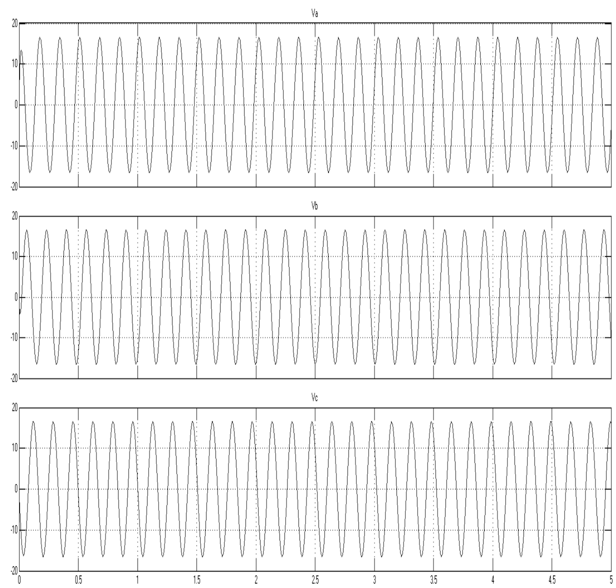

Fig.7.b) Three phase output voltage of Wind model

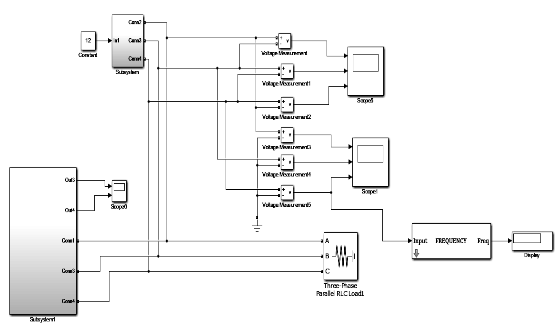

Fig.8. Sub-system of integrated solar and wind model.

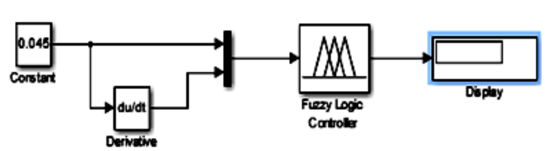

Fig.9.a) Fuzzy logic Controller

In figure9.a) the frequency deviation and the derivative of frequency deviation are given as the input to the Fuzzy logic controller unit .

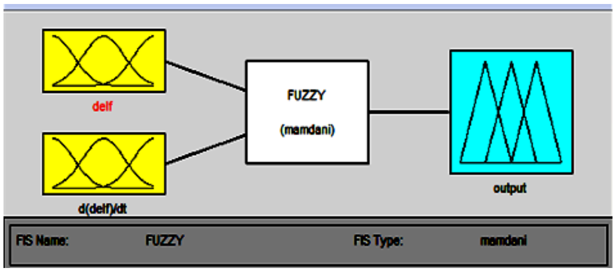

Fig.9.b).Input and Output Function of Fuzzy

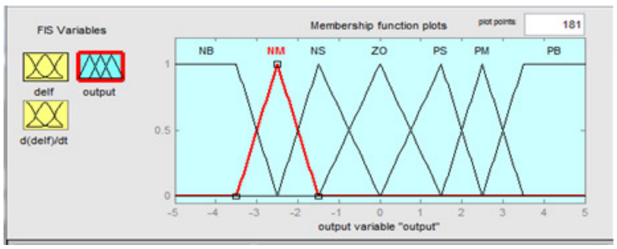

Fig.9.c). Output Membership Function of Fuzzy

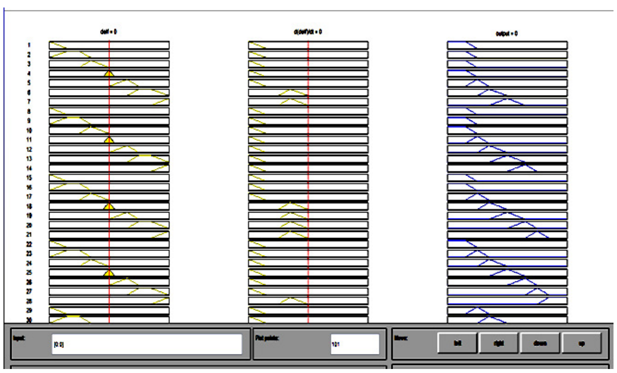

Fig.9.d).Rule Base

Fig.10.a) ANFIS TRAINING DATA

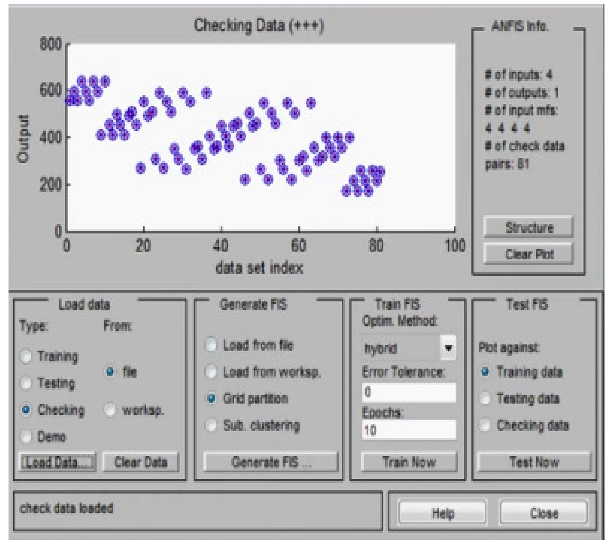

Fig.10.b) ANFIS OUTPUT

V. CONCLUSION AND FUTURE SCOPE

An isolated wind-solar based microgrid is considered and ANFIS controller is implemented for load frequency control in an isolated microgrid. The ANFIS controller improves the performance of the LFC system and it has better damping performance over PID and other conventional controllers. The settling time of frequency deviation is reduced for small disturbances and improves the dynamic response of the system. The proposed controller improves the frequency stability even with disturbances produced by both renewable energy sources and load. As neuro-fuzzy system combines the abilities of the neural network and fuzzy system, the membership function of fuzzy controller will change accordingly with the changing environment making the system more adaptive and robust. Further the performance of the controller depends upon the training data. The future work can be extended to extract the training data from the real time and modify the rules.

V.APPENDIX

The electrical parameters used for simulation are given.

TABLE I
ELECTRICAL PARAMETERS OF A SOLAR CELL

PARAMETER	VALUE
Short Circuit Current (I_{SC})	7.34 A
Open Circuit Voltage(V_{SC})	0.6 V
Irradiance(G)	1000 W/m²
No of cells in Series	16
Reference Temperature	298

PARAMETER	VALUE
Peak Power (W_p)	85.21 W
Open Circuit Voltage(V_{SC})	9.263 V
Irradiance	1000 W
No of cells in Series	16
Reference Temperature	298

TABLE II
ELECTRICAL PARAMETERS OF BUCK-BOOST CONVERTER

PARAMETER	VALUES
Duty Cycle(A)	0.55
Input Dc Voltage(V)	9.263V
Inductance(L)	$10e^{-3}$H
Capacitance(C)	50 e^{-3}F
Resistance(R)	100Ω

TABLE III
ELECTRICAL PARAMETERS OF WIND MODEL

PARAMETERS	VALUE
Generator speed	1.2 pu
Pitch Angle	0
Wind Speed	12m/s
Output Voltage	28.34 V

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