PERFORMANCE ANALYSIS OF ANFIS CONTROLLER BASED REACTIVE POWER COMPENSATOR FOR GRID CONNECTED HYBRID GENERATION SYSTEM

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Abstract

This paper presents Adaptive Neuro – Fuzzy Inference system (ANFIS) based control scheme to improve the performance of grid connected hybrid microgrid system. The proposed system consists of solar, wind, Static VAR Compensator (SVC) and load. Distributed Energy Resources (DERs) such as solar and wind which are connected in the microgrid will meet the power demand. Static Var Compensators (SVC) is used to compensate the reactive power, reduce oscillation and to improve grid voltage. The change in solar irradiance is considered and Maximum Power Point tracking (MPPT) scheme is used to extract maximum power from PV system. Permanent Magnet Synchronous Generator coupled with variable speed wind turbine is connected to grid. ANFIS is a adaptive and non-linear controller. It is more accurate and has the merits of both neural network and Fuzzy Inference systems. The main objective of proposed simulation model is focused on SVC based hybrid PV / Wind power system integrated with microgrid power network using ANFIS intelligent controller. The ANFIS intelligent controller monitors the power grid every half cycle and generates the control signal for microgrid integrated inverter for maintaining synchronization of grid and hybrid system at various operating conditions. The proposed ANFIS controller also reduces the THD (Total Harmonic Distortion) value of voltage and current profile of Point of Common Coupling (PCC) as well as load distribution side also. Simulation is carried out in MATLAB/Simulink environment. The robustness of this controller scheme is verified and MPPT performance of wind, MPPT performance of PV, voltage on distribution side, power extraction from PV and wind under variable load and environmental condition of the system are improved.

Keywords: Hybrid system, ANFIS based SVC, Grid connected, Power Quality

1. Introduction

A microgrid is a small – scale power production and delivery system comprising of Distributed Generation (DG), loads and Distributed Storage (DS)[1]. The benefits of the microgrid are reduction in harmful emissions, more reliable with high quality of power, low cost and higher efficiency. Microgrids are restricting the extension of power lines because they are able to supply local loads. Microgrids are operated in either grid – connected mode or islanded mode. In normal operating conditions or grid connected mode, a microgrid is connected in parallel with the power grid and the power is exchanged between power grid and microgrid based on demand and supply in the microgrid. In islanded mode, microgrid is disconnected from the power grid and it operates independently when a fault occurs in the power grid. Energy management is the most important role in microgrid in both grid connected and islanded modes. In islanded mode, microgrid required to meet the demand by increasing the generation or load sharing [2]. In grid-connected mode, the power grid is required to meet the demand. In most of the grid – connected system, main grid is used as back – up system. When there is insufficient supply from the renewable sources, main grid will supply power to microgrid. Such systems are designed to meet the local load to reduce the loss and provide quality of power. The different types of DER are connected in microgrid such as solar, wind, fuel cell and batteries. The control strategies used for hybrid system is different from the conventional system[3].

The implementation of microgrid with storage, challenges on microgrid and current control technology are discussed [4]. The intelligent Maximum Power Point Tracking (MPPT) Controller have been developed to control the real power for attaining quick and stable response [5]. Optimal design of isolated or grid –

connected hybrid system have been developed and steady state of the system was analysed[6]

Now- a days Solar Energy plays an important role to meet the power demand. Installed capacity can be increased because renewable energy sources are much cheaper and more efficient. But PV cells have poor power density, low conversion efficiency and higher cost compared to Wind Energy Conversion System (WECS). The maximum power point of Photovoltaic array varies with irradiance level. The Perturb & Observation (P&O) based MPPT algorithm is used to obtain the maximum power point due to its ease of implementation [7]. The conventional methods are low cost and very simple such as P&O, incremental conductance hill climping and etc. The intelligent methods have high accuracy but process is very complex such as Fuzzy Logic Control (FLC), Artificial Neural networks (ANN) and optimum Gradient method[8]. These techniques are not stable and also difficult to implement. FLC mainly depends on fine tuning membership function. NN takes long training process and convergence time. The ANFIS controller integrates merits of ANN and FIS. ANFIS has the features of self learning skills, parallel processing and adaptation.

In WECS, Variable Speed Wind Generators (VSWGs) have low mechanical stress, low noise, increased power capture, higher efficiency and higher control ability. Switched reluctance generator, Doubly fed Induction generator, Permanent Magnet Synchronous Generator(PMSG) are used as VSWGs. PMSG plays important role because of its high power density, high power factor operation, lower maintenance, lower loss and efficiency and lower cost[9,10]. PMSG is connected to the power grid through back to back voltage source converter connected through a common link. Generator side converter and grid side inverter are controlled by PI Controllers. PI controllers are high sensitive to non linear system dynamics and parameter variation. But tuning of PI controller is very cumbersome. Evolutionary programming algorithm such as Genetic algorithm (GA), Particle Swarm Optimization (PSO) has been used to fine tune PI parameters [11]. Now – a day's artificial intelligence techniques such as FLC, NN and ANFIS are used for controlling non linear system [12]. A wind generation system has been developed with PI Controller for maximum wind power extraction and neural network for wind speed measurement [13].During transient study, speed tracking error and power deviation are large. A radial basis function network is able to approximate non linearity to an infinite degree, and also able to carry out parallel computing, learning and fault tolerance [14]. It is very fast and easy realization.

In a grid – connected hybrid system, power electronic inverters are used for power conversion, controlling and grid connection. Pulse Width Modulation (PWM) based voltage source inverters (VSI) are applied in both wind and PV systems. So total harmonic distortion, high power factor and fast response are mainly depend on control strategy adopted for grid connected inverters.[15,16].

In this paper, PV and wind are considered as distributed energy resources. SVC is used for reactive power compensation. Traditional MPPT is applied to PV system and Wind turbine. ANFIS – PSO based MPPT is proposed for faster convergence and more accuracy. A PSO based learning procedure is used to identify ANFIS parameters.

The ANFIS intelligent controller is monitoring the power grid every half cycle and generates the control signal for microgrid integrated inverter for maintaining synchronization with hybrid PV and wind power system at various operating conditions. The proposed ANFIS controller also reduce the THD value of voltage and current profile of PCC of hybrid PV and wind energy system as well as load distribution side also. The proposed renewable energy based micro power grid compensates the reactive power, improving the power quality and voltage regulation as well as reducing the THD of voltage and current profile through ANFIS controlled SVC device. The proposed system has been simulated and analysed its performance under various conditions.

2. System Overview

The proposed hybrid system is shown in Fig. 1. It consists of PV, WECS, SVC and Load. Dynamic models of main components are developed using MATLAB/SIMULINK.

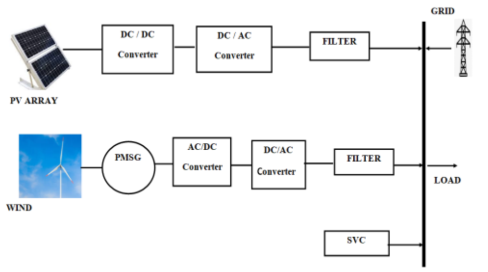


Fig. 1 Proposed Hybrid System

2.1. PV cell

Solar cell is a current source with antiparallel diodes which is having the characteristics similar to PN junction diode. The current source magnitude is proportional to solar irradiance. The terminal voltage and current are given by

$$V_{PV} = \frac{nKT}{q} ln\left(\frac{I_{sc}}{I_{PV}} + 1\right) \quad (1)$$

$$I_{PV} = I_{sc} - I_d \left[exp\left(\frac{q(V_{PV} + I_{PV}R_S)}{nKT}\right) - 1\right] - \frac{V_{PV} + I_{sc}R_s}{R_{sh}} \quad (2)$$

Where V_{PV} is the terminal voltage, n is the diode ideality factor, T is the array temperature, q is charge, I_{SC} is the induced light current, I_{PV} is the terminal current, I_d is diode saturation current, K is the Boltzmann constant ($1.38x10^{-23}$), R_{sh} is the shunt resistance, R_s is series resistance. I_{sc} depends on temperature (T) and irradiance level S, while saturation current and terminal voltage depends on Temperature only. The PV array current is the non linear function of temperature, irradiance and PV array voltage. Equivalent circuit of solar cell is shown in fig.2.

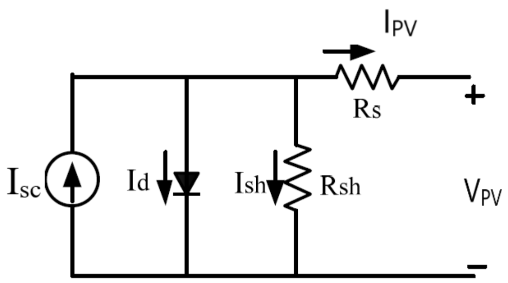


Fig.2. Equivalent Circuit of Solar cell

The output characteristics of solar cell are mainly depend on irradiation and temperature. Equation 1&2 shows that solar cell has the non linear characteristics. V – P characteristics is shown in Fig.3

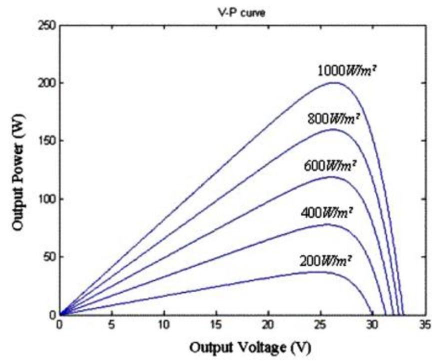


Fig.3. V-P Characterisctics of Solar cell

2.2 Wind Energy Conversion System

Wind energy is converted into mechanical energy in wind turbine and then it is converted into electrical energy. Power electronic devices are connected between wind turbine and microgrid to extract maximum power from Wind Turbine Generator (WTG). Wind turbine output power is restricted by its aerodynamics. The mechanical power is calculated by using

$$P_m = \frac{1}{2}\rho\pi R^2 C_p(\lambda, \beta) V_\omega^3 \quad (3)$$

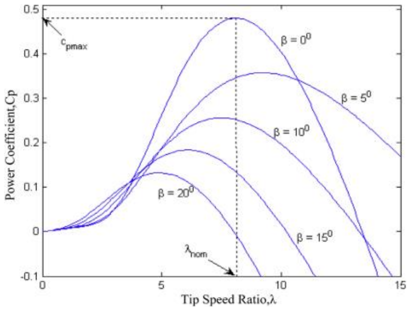
Where R is the rotor radius (m), ρ is the air density (Kg/m^3), V_ω is the wind velocity (m/s), C_p is the power coefficient and it is the function of pitch angle β(deg) and tip – speed ratio λ.

Tip speed ratio is given by

$$\lambda = \frac{\omega_r r}{V_\omega} \quad (4)$$

Where ω_r is the turbine speed (rad/s) and r is the turbine blade radius (m).

The power coefficient depends on turbine speed, wind speed and pitch angle. The variation of power coefficient will modify the extracted power from the wind. When C_p is 1, wind energy will be fully extracted by the wind turbine as useful energy. A variable speed wind turbine is considered in this paper, in which output power can be regulated by pitch angle controller. The variation between C_p and λ for different pitch angle (β) is shown in fig.4



. Fig.4 $C_p - \lambda$ of wind turbine for variable pitch angle

Power coefficient is defined as

$$C_p = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)e^{\frac{-18.4}{\lambda_i}} \quad (5)$$

$$\lambda_i = \frac{1}{\frac{1}{\lambda-0.02\beta}-\frac{0.003}{\beta^3+1}} \quad (6)$$

From the above equations, When β=0, maximum power coefficient (C_{pmax}=0.48)that corresponds to optimum value of tip speed ratio (λ_{opt} =8.9) is calculated and the control objective of maximum power extraction is derived as

$$P_{max} = \frac{1}{2\lambda_{opt}^3}\pi\rho C_{pmax} r^5 \omega_{opt}^3 \quad (7)$$

3. Control Strategy of Grid Connected System

3.1 PV System

The output of Solar cell depends on array voltage, temperature and irradiation. The traditional MPPT Controller is used to track the maximum power with nominal operating voltage. MPPT Controller is also used to maintain the constant voltage across the load. Many control algorithms are used in MPPT controller such as incremental conductance, P & O method, Fuzzy logic control, gradient method and ANFIS. These techniques obtain maximum power based on reference voltage. In PV array, P – V relation is non linear. ANFIS is the most powerful tool for solving non linear function which integrates the merits of ANN and FIS. ANFIS has the features of self learning skills, parallel processing and adaptation. So it track the maximum power quickly with high accuracy on various environmental condition. Fig. 5 shows the control block diagram for PV system.

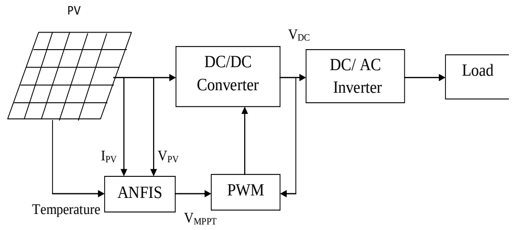


Fig.5 Control block diagram of PV system

3.2 Wind Energy Conversion System

The output of WECS depends on wind speed, turbine speed and pitch angle. The maximum power from wind turbine is extracted by generator side converter. This converter is controlled by MPPT techniques and control algorithm used in MPPT is ANFIS. As this converter is connected to the generator, d –axis stator current is proportional to reactive power ans q – axis stator current is directly proportional to real power. To achieve unity power factor, reactive power set point is set to zero and active power set point is determined by ANFIS. The ANFIS control scheme is used to control generator side inverter. The controllers are used to generate dq axes reference voltage. These reference voltages are converted into three phase voltage using transformation angle(θ). Three phase voltages are used to generate PWM signals which are given as gate pulse to the converter. Fig. 6 shows the control block diagram for WECS system.

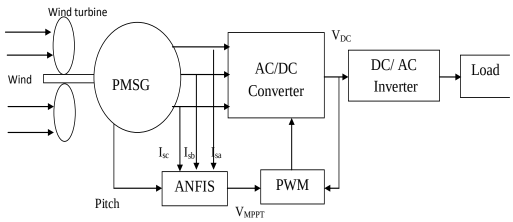


Fig.6. Block diagram for controlling WECS

3.3. Grid side Inverters and SVC

The terminal voltage at grid side is controlled by maintaining DC link voltage as constant on grid side inverter. The q axis current component is used for controlling reactive power and d axis current component is used to maintain the DC link voltage. The reactive power set point is set in such a way that grid voltage at PCC remains constant. ANFIS controller is used to control grid side inverter and SVC. Separate ANFIS controller is used for grid side inverter and SVC. The controllers are used to generate dq axes reference voltage. These reference voltages are converted into three phase voltage using transformation angle(θ). Three phase voltages are used to generate PWM signals which are given as gate pulse to the grid side inverters.

4. ANFIS Design

ANFIS is an intelligent system which incorporates the neural network and Fuzzy logic control. The set of input and output data are given initially to derive fuzzy model.Fuzzy logic tool box in MATLAB is used to find membership function parameter. The architecture of ANFIS is given in fig. 7. The proposed ANFIS model is shown in fig. 8

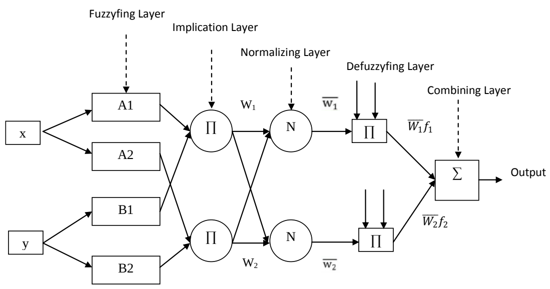


Fig. 7 Generalized architecture of ANFIS

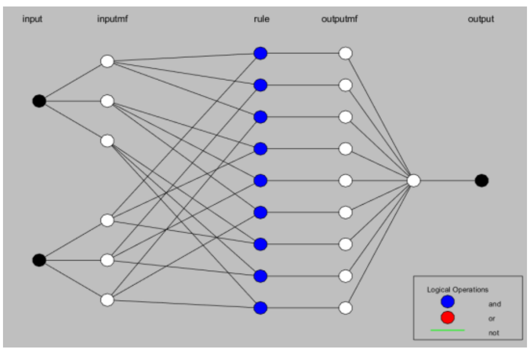


Fig. 8. Proposed model of ANFIS

In this work, fuzzy inference system has two sets of input data and one output and Sugeno type fuzzy inference system is used to train the data.

Rule 1: If (x is A_1) and (y is B_1) then $f_1 = p_1x+q_1y+r_1$

Rule 2:If (x is A_2) anf (y is B_2) then $f_2 = p_2x+q_2y+r_2$

Layer 1: It is fuzzification layer. If x and y are the two inputs to node m(m=1,2,3,..) of layer 1 then

$O^1_{Am} = \mu_{Am}(x)$ and $O^1_{Bm} = \mu_{Bm}(y)$

Where O^1_{Am} and O^1_{Bm} are the degree of membership functions of the Am and Bm respectively.

Layer 2: In this layer nodes are fixed node which is used to calculate firing strength w_i of the rule. The output of this layer from each node is the product of all input signals and is given by

$w_i = \mu_{Am}(x) \times \mu_{Bm}(y)$ where i, m=1,2,3…

Layer 3: In this layer, each nodes are fixed. The normalized firing strength are calculated and and given to next layer. The output of this layer is given by

$$\overline{w_i} = \frac{w_i}{w_1+w_2+w_3+\cdots} \quad \text{where } i=1,2,3,\ldots \qquad (12)$$

Layer 4: In this layer, each node is a adaptive node and node function is called as defuzzification layer. The output of this layer is given by

$$\overline{w_i}f_i = \overline{w_i}(p_ix+q_iy+r_i) \quad \text{where } i=1,2,3,\ldots \qquad (13)$$

Layer 5: This layer consists of only one fixed node. The final output of the controller is obtained from this node and is the summation of all inputs to this node. This is given by

$$f = \sum \overline{w_i}f_i = \frac{\sum w_i f_i}{f_i} \qquad (14)$$

5. Simulation results

The proposed hybrid microgrid system shown in fig.1 is developed in the MATLAB / Simpower environment. The proposed system has been simulated and its performance under various conditions is analyzed. Many tests are conducted to show its performance and results are compared with various MPPT schemes.

5.1 MPPT performance

5.1.1. MPPT performance of PV system

The hybrid system is simulated with constant temperature, irradiation and load. ANFIS (8) controller gives better performance when compared to other controller such as PI, P &O. It doesn't (9) oscillate. It has better transient response and error is very small. It reaches its steady state quickly. The average power obtained is 101.28 KW which is 1.08% more than PSO based MPPT controller. MPPT performance is given in fig. 9. Comparison of MPPT performance is given in table 1.

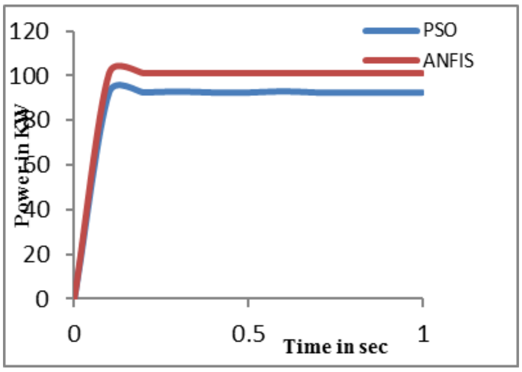


Fig.9 MPPT performance of PV System

Table 1

Performance comparison of PV array

Type of Controller	Maximum power extracted (KW)	Error (%)	Transient Response(s)	Power extraction efficiency(%)
ANFIS	101.28	0.87	0.1	87
PSO	92.69	9.7	0.3	80

5.1.2. MPPT performance of WECS system

System is simulated with constant load with variable wind speed and irradiation. The output power from WECS is given in fig. 10. It shows that ANFIS controller provides output power with less oscillation and smaller vibration. PI controller fluctuates more when compared to ANFIS. The average power obtained is 30.3 KW which is 1.14 more than RBFNSM controller.

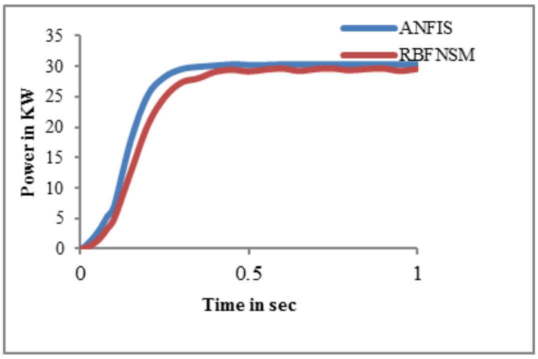


Fig.10. MPPT Performance of WECS

Table 2

Performance comparison of WECS

Type of Controller	Maximum power extracted (KW)	Error in Cp %	Transient Response(s)	Power extraction efficiency (%)
ANFIS	30.3	7.1	0.3	87
RBFNSM	28.6	25.2	0.55	82

5.2 Sudden load Change

When load changes from 50 KW to 60 KW at 0.5s, hybrid system reaches its stable state quickly within 0.005s and oscillation in voltage is also within the prescribed limit. It is shown in fig. 11. Voltage variation is given in fig.11 which falls from 0.995 to 0.986 pu. So the proposed method tracks more stable power from both wind and PV under variable conditions.

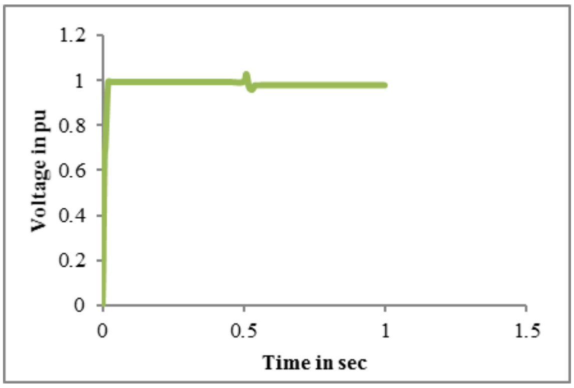


Fig.11. Variation in voltage in pu

5.3. MPPT under variable condition

In this hybrid system, irradiance level changing from 900W/m^2 to 1000 W/m^2, wind speed varies from 5 m/s to 12 m/s at t=0.5s and the load is 50 KW. The simulation was carried out with constant load. The output power from PV is shown in fig.12 Solar power reduces around 15 KW and Wind power increases from 0 to around 30.4KW.

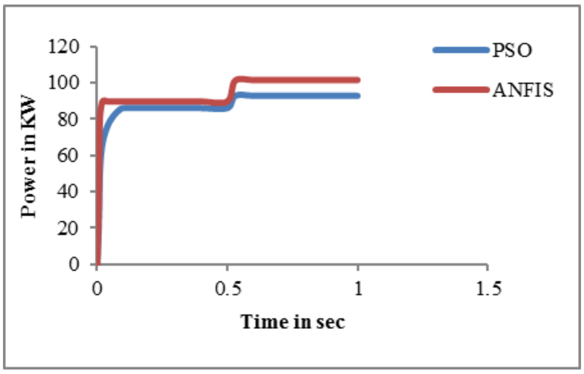


Fig.13 PV power variation for changing the irradiation level

5.4 Effect of SVC

SVC is connected at load end. It is controlled by ANFIS controller based on load current. It is mainly used for reactive power compensation. This reduces harmonics distribution used for reactive power compensation. This reduces oscillation in voltage and current at PCC. So voltage is maintained constant and within the requirement IEEE 1547 standard. THD of voltage and current is given in table 3.

Table 3.

Controllers	THD of Voltage (%)	THD of Current (%)
ANFIS	1.03	0.53
PSO, RBFNSM	3.41	5.2

6. Conclusion

In this paper, grid connected hybrid generation system with PV and Wind is proposed and implemented. The simulation model is developed using MATLAB/Simulink. The proposed ANFIS controller is applied to PV, wind and SVC. The proposed scheme is compared with PSO based MPPT scheme for PV and RBFSM for wind. The performance of grid connected hybrid system is simulated and analysed under variable load and environmental condition. It shows that grid connected hybrid system is well controlled by ANFIS Controller. ANFIS Controller tracks the maximum power from the wind turbine and solar panals, and also maintains the bus voltage as constant under variable load and environmental condition. Power sharing in the proposed scheme is more efficient and faster than PSO and RBFNSM . The oscillation is less in the proposed scheme and THD factor of current is 0.53% and voltage is more stable under different loading condition and is maintained as 0.98 pu with THD factor of 1.03%.

7. References

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