Artificial Neural Network Controller Strategy for Improving DC Link Voltage of Grid Connected Hybrid PV-Wind Generation Systems

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Abstract: This paper presents a power system, consisting of photovoltaic (PV) station and wind farm integrated by ac bus, connected to the grid. The load gets power from both the sources and maximum power is tracked by maximum power point techniques (MPPT) during any changes in the environment. The paper explores how MPPT techniques help power system in tracking power from PV and wind in the conditions of different solar irradiances and different wind speeds. This paper’s objective is to show the improvement in step response of dc link voltage by artificial neural network (ANN) controller. The control method significantly maintains constant grid voltage ensuring unity power factor even during climatic conditions variation. The whole system is simulated using matlab/simulink software and the results compare the proposed system with existing controller i.e., Proportional Integral (PI). The results show the efficient performance of ANN controller than PI controller.

Index Terms: Solar array, PV, wind energy, MPPT, Fuzzy Logic Controller, ANN controller.

I. INTRODUCTION:

As a result of fossil fuel constraints and worldwide greenhouse impacts, renewable energy needs have grown considerably. Among numerous types of non-conventional energies are good potential sources for people. Due to the growth of the power electronics technology, the photovoltaic and wind power systems have been quickly enhanced [1][2]. The electricity generations are complimentary due to the intermediate nature of PV and wind. The combination PV/wind system consequently provides continuous electricity [3], [4] more dependable than any single source. A large battery bank is required to collect maximum energy from solar or wind turbines and to supply constant electricity. But because of their huge dimensions, high masses, high cost, shorter life cycles and chemical pollution, the usage of batteries is not environmentally advantageous. The ideal way to use PV array and wind turbine electrical energy is to connect it directly to the power source. For this combined power network the MPPT function is needed, as the PV-Array output tension is different from the wind turbine and requires a DC/DC converter and a DC/AC inverter.

Over the years, various literatures such as[5] have been given with the PV/Wind combined power network linked to grid, models and control mechanisms. In this case, the author has introduced the...
PV/Wind hybrid power network. In the PV/wind combined energy network, Quinary Asymmetric Batteries were suggested [6]. The [7] presents an independent PV/Wind system with sliding mode control. The most widely utilized PV/Wind power systems is the Dual fed induction generator. As the power is easy to build and activated and reactive to take topmost power from the wind farm [8,9], it’s regulated and able to extract maximal energy. A number of studies and research have been studied in the combination of PV plant and wind-hinged DFIG as a combined system [10, 11]. Among these, a hybrid PV and DFIG energy system for sustainable electricity to faraway places has been launched [10]. Kumar [11] provided the simulation study for integration of PV and DFIG as a combined power network. Recently, control techniques were developed to address concerns of injecting power quality and large power extraction from the combined power system under variable ambient circumstances. The disturbance was investigated and the MPPT method of getting maximum power out of PV systems was seen during fluctuation of the solar irradiance [12].

A dc/dc Multi-input and full-bridge inverter systems connected to the PV/wind grid. The dc/dc converter with multi-insert uses maximum power either individually or simultaneously from the PV or wind turbine array. The complete bridge inverter injects almost sinusoidal current into the grid so that the power flow from input to output is balanced. The dc bus generates significant voltage fluctuation because of the constant change in input power of the PV array and the wind turbine. The sinus current is then adjusted to the dc bus tension.

In this paper the mixed PV and wind power source combined with a system design and control method for grid modelling is analyzed. The facility includes a 1 MW PV station and a 9 MW wind farm linked to the main AC bus, thus improving system efficiency. Generated electricity. The MPPT Technology is used to acquire the maximum power from the hybrid system for both PV and wind resources as environmental circumstances change. In diverse climatic conditions, such as solar radiation and wind speed, the efficacy and control of the hybrid power system are evaluated. And the step response by the artificial neural network (ANN) controller in relation to the dc link voltage is improved. The simulations show the efficacy of MPPT technology in extracting the greatest power in various environmental circumstances from the combined power network. Moreover, the system operates properly at the unit power factor since the injected wattles power of the system is zero. The system also successfully maintains the continuous grid voltage, regardless of environmental changes or hybrid power input. And the dc link voltage by both the controllers is depicted in the results.

2. PV-WIND HYBRID POWER NETWORK

The network setup of the combined power network explained is illustrated in figure 1. The network comprised of a 1 MW photovoltaic station and a 9 MW wind farm located at various points. The PV plant and wind farm are integrated by the head PCC node, which injects power and improves the system performance. The PV station contains several PV modules connected in the combination of parallel-series to obtain the desired power. In addition, the PV system is associated with the DC-DC booster converter and the DC-AC inverter for converting the DC power generated into AC. MPPT incremental conductance technology is used to extract maximum power in a varying solar radiance from PV station. The PV station is also connected via 260V/25KV Δ/Y transformer with the PCC bus. And the wind farm includes a DFIG aggregate equivalent, which is powered by a top most wind turbine. In addition, the wind farm contains a grid-side converter and rotor-side converters to maintain the constant DC-node voltage and to extract large power out of the wind turbine respectively. A modified MPPT technology is implemented which allows the high wind power capture during wind speed changes. The wind farm is linked to the PCC-node through the 575V/25KV/Y transformer. The combined power network maintains unity power factor throughout and delivers watt power to the electrical grid along transmission lines of 30 km and a 25KV/120KV Y/ transformer.
3. PV/SOLAR ANALYSIS

A. Solar Analysis

The PV station comprises many series linked PV modules to achieve the required amount of voltage. And all PV threads are linked to form a PV array in parallel in order to provide the necessary electricity. In order to capture the high energy from solar irradiation fluctuations, each pv array is linked to a DC/DC boost converter. These PV arrays are connected in conjunction with the main DC/AC converter to control the watt power in the grid and achieve the watt power required. With enhanced effectiveness and reduced losses, consistent DC connection voltage [10], this analysis is cost-effective. Figure 2 illustrates the basic PV concept.

B. Incremental Conductance Method

In photovoltaic conversion systems, MPPT strategies are critical. Given the time variation in the intensity of solar irradiation, MPPT is used to extract large power from the PV array under solar irradiance variation. The MPPT technology is therefore aimed at controlling the boost converter thus at MPP PV array is operated.

Fig.1: Solar-wind combined power network’s configuration

Fig.2: Ideal Photovoltaic model
The MPPT incremental conductance approach was used to obtain large power because of its simplicity and benefit of offering high show with fast variations in solar irradiation. Figure 3 depicts the appropriate incremental conductance flowchart.

C. Artificial Neural Network (ANN) Controller

In order to detect distorted signal quickly, ANN is the effective controller. Under parametric variability, the traditional controller doesn’t always work. It is a neuron cluster with learning and adoption capacity. With the adjustment of the weight value, neurons are trained to handle a certain function. The Levenberg Marquardt Back Propagation technique and the minimized mean square error are used for training. In a hybrid version with a distorted supply voltage, rapid convergence and good dynamic responsiveness are obtained. The suggested control framework includes multilayer neural networks. It has a single neuron input layer, a 20-neuron hidden layer, and a neuron output layer.

The input vector is provided as
\[ c = [V_e(k)] \]  

The error signal at sampling time (kth) is:
\[ V_e(k) = V_{dc}^* - V_{dc}(k) \]  

\[ x_1 = V_e(k) ; \quad x_2 = \frac{\delta x_1}{\delta k} \]  

The following gives output error
\[ Z(k) = V_{out}(k) - V_{out}(k - 1) \]  

The signal control generates neuron cell is
\[ c(k) = c(k - 1) + \sum \sum w_i(k)x_i(k) \]
Neuron cell’s weight at sampling time \((k+1)\) is expressed as

\[
w_i(k + 1) = (1 - r)w_i(k) + \eta Z(k)c(k)x_i(k)
\]

(6)

where ‘\(\eta\)’ is learning rate and ‘\(r\)’ is constant for convergence.

To obtain change weight at step \((k)\), uses equations (4) and (5), expressed as

\[
\Delta w_i(k) = w_i(k + 1) - w_i(k) = -r[w_i(k) - \eta Z(k)x_i(k)u(k)/r]
\]

(7)

\(Fi\) represents signals of post-synaptic and pre-synaptic as,

\[
\Delta w_i(k) = F_i(I_{isp}(k), x_i(k))
\]

(8)

\[
\frac{\delta F_i}{\delta w_i} = w_i(k) - \eta Z(k)x_i(k)u(k)/r
\]

(9)

Change of weight at \(k\)th step is represented as

\[
\Delta w_i(k) = -r \frac{\delta F_i(k)}{\delta w_i(k)}
\]

(10)

The reference signal is obtained after it is trained and the controller output \(i_{sp}\) generates gating pulses by generating the referred three-phase source current.

4. WIND ENERGY SYSTEM

A. Wind Turbine Model

The function and characteristics of the wind turbine can be understood simply if the wind reaches the turbine with a constant velocity and uniform properties (e.g. temperature, density) and in the absence of the turbulence. Figure 4 shows the wind turbine characteristics at various wind speeds. The power fraction retrieved from the wind can be determined by a real wind turbine with the symbol \(C_p\) which means the performance or power coefficient. The actual mechanical output \(P_m\) of a wind turbine is shown as,

\[
P_m = C_p \left[ \frac{1}{2} \rho A v_w^3 \right] = \frac{1}{2} \rho \pi R^2 v_w^3 C_p(\lambda, \beta)
\]

(11)

Where \(R\) indicates wind turbine’s blade radius \((m)\), \(v_w\) represents wind speed \((m/s)\) and \(\rho\) denotes air density \((kg/m^3)\)

The wind turbine's performance coefficient \((C_p)\) depends on the aerodynamics blade and is representative of the wind turbine’s efficiency. The coefficient of performance \((C_p)\) is as follows:

\[
C_p(\lambda, \beta) = 0.5176 \left( \frac{116}{\lambda_i^4} - 0.4 \beta - 5 \right) e^{-\frac{11}{4}} + 0.0068 \lambda
\]

(12)

\[
\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08 \beta} \frac{0.035}{\beta^3 + 1}
\]

(13)
B. Modified MPPT Strategy

Highest power station is extracted when the rotor rotates at its proper speed. As a consequence, if the wind speed fluctuates, the MPPT technique estimates the ideal speed to maximize power output from the wind turbine. Because most MPPT approaches rely on observable wind turbine and speed characteristics, the accuracy of the MPPT method is impacted by windmill mismodeling and sensor precision. This study offers a modified MPPT control technique for determining optimal rotational speed hinged on mechanical power measurement. The flow chart of the improved MPPT technique is shown in Figure 5.

The MPPT method first provides mechanical power values and optimal rotating speeds. The method then determines the appropriate rotational speed based on the present mechanical power. If a wind farm’s mechanical power exceeds 0.750 p.u., the ideal rotation speed is usually 1.20 p.u., signifying large power. The optimal rotational speed is calculated by Equation (4.6) when the mechanical power is less than 0.750 p.u. Without measuring wind speed, the improved MPPT control technique enables optimal rotating speed to correctly measure maximum power. The optimal rotational speed is given below:

\[
\omega_{\text{ref}} = \begin{cases} 
1.2 & \text{if } P_{\text{m,pu}} \geq 0.750 \\
-0.57\left(\frac{P_{\text{m,pu}}}{P_{\text{m,pu}}}\right)^2 + 1.42\left(\frac{P_{\text{m,pu}}}{P_{\text{m,pu}}}\right) + 0.51 & \text{if } P_{\text{m,pu}} < 0.750 
\end{cases}
\]  

(14)

Fig. 4: Wind Turbine Characteristics at Different Wind Speeds.

Fig. 5: Flowchart of the modified MPPT method.
5. SIMULATION RESULTS

In the Matlab / Simulink platform, the solar wind hybrid system is simulated during variations in environmental conditions, for the performance analysis of MPPT strategies and control methods. The dynamic performance during variations in solar irradiance and wind speed of PV stations and wind farms is investigated.

A. PV performance during solar irradiance variation with PI controller

Various solar radiation conditions are presented for the evaluation of the performance of an MPPT algorithm: from 1000 W/m² to 250 W/m² as in figure 6(a). The solar radiation changes influences the photovoltaic current $I_{pv}$, as shown in figure 6 (b) where the output current of the PV array decreases according to changes in the irradiance. Photovoltaic voltage $V_{pv}$ is also reduced by MPPT controller under changed irradiance conditions as in figure 6(c).

![Figure 6(a) Changes in solar irradiance](image)

![Figure 6(b) Variation of PV array current](image)

![Figure 6(c) Voltage of PV array](image)

![Figure 6(d) The active power and reactive power injected into the grid](image)
Fig: 6(e) The three phase current and voltage waveforms by PI controller.

Fig: 6(f). DC link voltage with PI controller.

Fig: 6(g) The power factor of the inverter with PI controller.

Figure 6(d) depicts the watt and wattles power injected with variations in solar irradiation from the PV installation. The active power varies as a result of solar radiation, whereas the injected wattles power is equal to zero. Figure 6(e) depicts unambiguous sinusoidal 3-phase waveforms for grid voltage and current. Figure 6(f) depicts the DC-bus voltage of the PI controller, which is somewhat greater than that of the ANN. Figure 6(g) depicts the inverter power factor as measured by the PI.

**B. PV performance during solar irradiance variation with ANN controller**

As shown in Figure 7 (a), the ANN controller embeds grid voltage and power. The voltage of the DC-bus in which the setting time is zero by ANN controller is displayed in Figure 7(b). In figure 7(c) and in figure 7(d), the inverter’s power factor by ANN controller shows the PV station’s performance during solar irradiance changes.
Fig: 7(a) The three phase current and voltage waveforms with ANN.

Fig: 7(b). DC link voltage with ANN.

Fig: 7(c) The power factor of the inverter with ANN.

Fig: 7(d) PV station’s efficiency during solar irradiance variation.

C. Wind farm performance with wind speed variation

The wind farm’s dynamic performance with changes in wind speed is seen below. Figure 8(a) depicts the fluctuation in wind velocity. GSC controllers maintained consistent DC bus voltage even when wind speeds varied, as seen in Figure 8(b).
Fig: 8 (a) Wind speed profile.

Fig: 8 (b) The DC-link voltage of DFIG.

Fig: 8 (c) Watt and wattles power injected from wind farm.

Fig: 8 (d) Power factor of the inverter.

Fig: 8 (e) Injected current from wind farm.
The watt and wattles power of wind farm, when wind varies, is presented in Figure 8(c). The watt power injected tends to monitor wind speed change. The MPPT control tracks the $\omega_{\text{ref}}$ accurately and shows high watt power. While the wattles power injected is kept zero, in figure 8(d), the wind farm operates at a unity factor. Figure 8(e) shows injected waveforms of the current and the RSC controller controls the current amplitude as an active power injection function.

6. CONCLUSION

The PV-WIND hybrid power system connected to the grid is presented in this paper. In Matlab/Simulink software the simulation of the system proposed has been implemented. During variations in solar irradiance, the MPPT incremental conductance technique was used for the extraction of maximum PV power. And an enhanced MPPT control strategy was used to deduct maximum wind speeds from the wind farm according to the measurement of mechanical energy. The DC-link voltage controller of the VSI is successfully controlled by both PI and ANN controllers. The simulations results showed a better step response of dc-link voltage by ANN controller than the existing PI controller. While the injected wattles power is zero, the control network still managed to maintain the combined power system at unity power factor. In the PCC bus, the voltage is also kept constant, irrespective of the weather conditions and the amount of active power generated.

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