Neural Network based Voltage and Frequency Controller for Standalone Wind Power System

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Abstract—This paper deals with an artificial neural network based control of the voltage and frequency (VF) of autonomous wind power generation using an isolated asynchronous generator (IAG). The proposed controller has bidirectional active and reactive power flow capability along with battery energy storage system by which it controls the system voltage and frequency with variation of consumer loads and speed of wind. The proposed system is modelled and simulated in MATLAB using Simulink. The proposed controller has additional capability of harmonic elimination and load balancing and hence power quality can be improved.

Key words: Battery energy storage system, isolated asynchronous generator, voltage and frequency controller, wind energy conversion system

I. INTRODUCTION

Some of the areas are remote so that it is very difficult for those areas to access main power grid. So it is necessary to meet the demand of remote areas. Wind is the most prominent source of energy available. We can easily exploit by using asynchronous generator. Squirrel cage induction are low cost, robust and simple in its construction. Wind speed and load are varying, so in order to maintain voltage and frequency here employing a voltage and frequency controller for standalone wind power generating systems.

The proposed voltage and frequency controller is having bidirectional active and reactive power flow capability by which it controls the system voltage and frequency with variation of consumer loads and wind. It has additional capability of harmonic elimination and load balancing. The performance is demonstrated using standard MATLAB software

II. SYSTEM CONFIGURATION

The complete off grid stand-alone system with asynchronous generator, wind turbine, excitation capacitor, balanced/unbalanced, linear/non-linear/dynamic consumer loads and proposed controller is shown in Fig.1. The proposed controller includes three-phase insulated gate bipolar junction transistor (IGBT) based voltage source converter (VSC) along with a battery at its dc link. The controller is connected at the point of common coupling (PCC) through the inter-facing inductor. The excitation capacitor is selected to generate the rated voltage at no-load while additional demand of reactive power is met by the controller.

Fig. 1: Schematic diagram of the proposed isolated wind energy system

III. CONTROL SCHEME

Fig. 2 demonstrates the control strategy of the proposed controller which is based on the generation of reference source currents. A new ANN based technique for VFC is proposed for IAG in isolated wind power generation.

The adaptive linear neuron (ADALINE) based controller is used for on-line estimation of reference generator currents. For extracting the three-phase reference generator currents, least mean square (LMS) algorithm based ADALINE is used, which is a fast and efficient method of current extraction. The reference generator currents are composed of the fundamental real power component (referring to the active power component) and the fundamental reactive power component (referring to the reactive power component). Three ADALINEs are used to extract the weight of three phase fundamental frequency real power component of load currents. The other three ADALINEs are used to extract the weight of three fundamental frequency reactive power components of load currents.

The LMS algorithm with on-line calculation of weights is used for VFC under perturbations of loads and wind speed. The in-phase and quadrature phase templates of the synchronized signals are estimated using sensed and filtered line voltages. The frequency proportional integral (PI) controller adjusts the weight of in-phase component of the three-phase generator currents, while the voltage PI controller adjusts the weight of quadrature component of the generator currents.
u_{eq} = (-u_{ap}\sqrt{3} + u_{bp} - u_{cp})/2\sqrt{3} \quad (4.6)

C. Extraction of Weights for Fundamental Active Power Component of Load Currents

The extraction of weights of fundamental active power component of the load currents is based on LMS algorithm and its training through ADALINE, which tracks the in-phase unit template to maintain minimum error. The weight of active component of the individual phase load current is estimated using LMS adoption algorithm. The estimation of weight is given as

\begin{align*}
W_{ap}(n) &= W_{ap}(n-1) + \eta (i_{La}(n) W_{ap}(n-1) u_{ap}(n)) u_{ap}(n) \quad (4.7) \\
W_{bp}(n) &= W_{bp}(n-1) + \eta (i_{Lb}(n) - W_{bp}(n-1) u_{bp}(n)) u_{bp}(n) \quad (4.8) \\
W_{cp}(n) &= W_{cp}(n-1) + \eta (i_{Lc}(n) - W_{cp}(n-1) u_{cp}(n)) u_{cp}(n) \quad (4.9)
\end{align*}

\eta is the convergence factor and it decides the rate of convergence and accuracy of estimation. The practical range varies between 0.001 and 1.0. Higher value of \eta increases the rate of convergence, but at the same time it leads to inaccurate results, whereas low value of \eta leads to accurate results with slow rate of convergence. The best trade-off value of \eta is observed in accuracy and rate of convergence at 0.01.

D. Extraction of Weights for Fundamental Reactive Power Component of Load Currents

The extraction of weights of fundamental reactive power component of the load currents is based on LMS algorithm and its training through ADALINE, which tracks the quadrature template to maintain minimum error. The estimation of weight is given as

\begin{align*}
W_{aq}(n) &= W_{aq}(n-1) + \eta (i_{La}(n) - W_{aq}(n-1) u_{aq}(n)) u_{aq}(n) \quad (4.10) \\
W_{bp}(n) &= W_{bp}(n-1) + \eta (i_{Lb}(n) - W_{bp}(n-1) u_{bp}(n) - W_{aq}(n-1) u_{aq}(n)) u_{bp}(n) \quad (4.11) \\
W_{cq}(n) &= W_{cq}(n-1) + \eta (i_{Lc}(n) - W_{cq}(n-1) u_{cq}(n)) u_{cq}(n) \quad (4.12)
\end{align*}

E. Estimation of Fundamental Active Power Component of Reference Generator Currents

The sum of instantaneous weight of the fundamental active power component of the load currents is subtracted from the output of the frequency PI controller to estimate the average weight of the fundamental reference active power component of the generator currents. The frequency error is given as

\begin{equation}
f_e(n) = f_{ref}(n) - f(n) \quad (4.13)
\end{equation}

Where f_{ref} is the reference frequency (i.e. 50 Hz in this case) and “f” is the frequency of the terminal voltage of an IAG. The instantaneous value of “f” is estimated as shown in Equation (5). The instantaneous frequency depends on wind turbine speed; however, this turbine speed is based on the instantaneous wind speed and the instantaneous active load present on the generator. Therefore, the output of the frequency controller is based on the requirement of necessary weight of active power component of the generator current for maintaining the system frequency constant. At the nth sampling instant, the output of the frequency PI controller is given as
\[ W_{fp}(n) = W_{fp}(n-1) + k_{pf}(f_c(n) - f_c(n-1)) + k_{pf}f_c(n) \]  
(4.14)

Therefore, the average weight for fundamental active power component of the reference generator current is given as

\[ W_p(n) = W_{fp}(n) - W_{ip}(n) \]  
(4.15)

These three-phase fundamental active power components of the reference generator currents are computed as

\[ i_{gap}^* = W_p u_{ap}, \]
\[ i_{gip}^* = W_p u_{bp}, \]
\[ i_{gcp}^* = W_p u_{cp} \]  
(4.16)

F. Estimation of Fundamental Reactive Power Component of Reference Generator Currents

The instantaneous weight sum for the fundamental reactive power component of the load currents is subtracted from the voltage PI controller output to estimate the average weight of the fundamental reactive power component of the reference generator currents. The ac voltage error at the \( n \)th

\[ V_{e}(n) = V_{fr}(n) - V_{r}(n) \]  
(4.17)

Where \( V_{fr}(n) \) is the amplitude of the reference ac terminal phase voltage and \( V_{r}(n) \) is the amplitude of the sensed three-phase ac voltage at PCC and is computed as given in Equation (2). The output of the voltage PI controller is intended to maintain a constant ac terminal voltage. The terminal voltage is a function of the reactive power. Therefore, to regulate the voltage, the output of voltage PI controller in terms of weight of reactive power component of the generator currents at the \( n \)th sampling instant is expressed as

\[ W_{eq}(n) = W_{eq}(n-1) + k_{pr}(V_{r}(n) - V_{r}(n-1) + k_{pr}V_{e}(n)) \]  
(4.18)

Where \( k_{pr} \) and \( k_{pq} \) are the proportional and integral gain constants of the PI controller, respectively. \( V_{r}(n-1) \) are the voltage errors in the \( n \)th and \( (n - 1) \)th sampling instant and \( W_{eq}(n) \) and \( W_{eq}(n-1) \) are the weights of output of voltage PI controller in the \( n \)th and \( (n - 1) \)th instant needed for voltage control.

Therefore, the average weight of fundamental reactive power component of the reference generator current is given as

\[ W_q(n) = W_{eq}(n) - W_{iq}(n) \]  
(4.19)

Three-phase fundamental reactive power components of the reference generator currents are given as

\[ i_{gag}^* = W_q u_{aq}, \]  
(4.20)
\[ i_{gba}^* = W_q u_{bp}, \]  
(4.21)
\[ i_{gcq}^* = W_q u_{cq} \]  
(4.22)

G. Estimation of Fundamental Reference Generator Currents

Three-phase fundamental reference generator currents are estimated for each phase as the vector sum of individual phase fundamental reactive active power component of the generator current and fundamental reference reactive power component of the generator current as follows:

\[ i_q^* = i_{gap}^* + i_{gag} \]  
(4.23)
\[ i_b^* = i_{gpb}^* + i_{gba} \]  
(4.24)
\[ i_c^* = i_{gcp}^* + i_{gcq} \]  
(4.23)

V. SIMULATION AND RESULTS

The proposed ANN based VFC along with fixed pitch wind turbine driven IAG is tested with balanced/ unbalanced linear/nonlinear three-phase four-wire loads. The performance of VFC is presented under dynamic conditions to validate the control algorithm. The suitability of the control algorithm is shown by demonstrating the ANN based control variables’ variations under no-load, unbalanced nonlinear loads and balanced nonlinear load conditions. In addition, the performance of VFC is tested with lagging power factor (pf) loads. The reactive power demand of the load as well as IAG is supplied by VSC of VFC. Model with voltage and frequency control is modelled using MATLAB for linear unbalanced loads. The results are given below and we can see distortion is very much reduced.

A. Performance of the Controller Feeding Linear loads

Similarly Fig. 4 Demonstrates the performance of the controller with 0.8 pf lagging reactive loads (balanced and unbalanced respectively) at fixed wind speed At 1 s load is given and at 1.2 s one phase of the load are opened and the load becomes unbalanced but voltage and current at the generator terminals remain balanced.
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Fig. 4: Performance of VFC controller with static load

B. Performance of the Controller Feeding Nonlinear loads

Fig. 5 demonstrates the performance of the controller with nonlinear load at fixed wind speed. A three-phase rectifier load with resistive element is applied and the generator terminal with minimal harmonic distortion which show the load balancing aspects of the controller. At 0.95 s one phase and later on at 1.1 s another phase of the load are opened and the load becomes unbalanced but voltage and current at the generator terminals remain balanced.

Fig. 5: Performance of VFC controller with Nonlinear load

VI. CONCLUSION

A new control algorithm for the voltage and frequency control of IAG has been presented in isolated WECS. It has been shown that a three-leg integrated VSC with a BESS is one of the best alternatives for VFC in constant speed IAG driven IWECS. The simplicity and inherited linearity of the control are some of the salient features of the new algorithm for VFC.

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