Adaptive Controller Based on LMS Algorithm for Grid-Connected and Islanding Inverters

Tatjana Nikolić, Goran Nikolić, and Branislav Petrović

Abstract - In the field of renewable energy, DC/AC inverters are crucial building blocks used in the various industrial and consumer devices. Grid connected power inverters should operate in synchronism with the grid voltage in order to get maximum active power. In this paper, the structure of a power system based on adaptive control is described. The main purpose of the adaptive controller is to continuously adapt the output signal of the inverter to the corresponding load and/or grid waveform. It is very important to enable the generation of appropriate excitation signal for the inverter. By involving adaptive controller the response time decreases and quality of power delivery to the load or grid increases. Matlab/Simulink model of the power system with adaptive control is used for simulation.

Keywords - DC/AC inverter, Pulse Width Modulation (PWM), Adaptive filter, System identification.

I. INTRODUCTION

Recently, there has been a pronounced increase of interest in the field of renewable energy. To meet the increased demand for electrical energy delivery alternative renewable energy sources with energy storage device (i.e. battery) are used. In an effort to utilize easily available solar energy effectively, the need for static inverters has increased significantly. With high energy efficiency and fast time response, inverters have possibility to convert DC energy stored in batteries to conventional controlled AC form. The applications require DC-AC power inverters with a high performance voltage regulation and high efficiency. To achieve these goals, power inverters need an optimal controller. The converted AC can be at any required voltage and frequency by using switching technique implemented by corresponding control circuits [1, 2]. With the rapid development of large-scale digital integrated circuits, power inverters are required to have a smaller area and a faster dynamic response [3].

Power inverters can be used as grid tie or stand-alone power sources. When the inverter is connected to the grid then the grid controls the amplitude and frequency of the inverter output and the inverter operates in current control mode. If the network is not available, the inverter will autonomously supply the load with adequate AC voltage in respect to amplitude and frequency. In this case, the inverter will control the voltage [4]. With aim to provide a correct operation of the power inverter connected to grid or/and load, with high stability and power quality, pulse width modulation (PWM) generator which drives the inverter is needed (see Fig. 1). The inverter will continuously generate the desired output signal that is consistent with the network waveform if it is excited by the appropriate input signal. Recently, research efforts have been devoted to system identification and adaptive and self-tuning control techniques for power converter applications [3, 5, 6]. The implementation of considered methods require significant signal processing, and higher computational complexity increases execution time and disables real-time operation. For this reason, there is still a need for a low complexity, online adaptive technique which can run continuously in closed loop, adapting to changes in the power system. In order to achieve this goal, an efficient design of an adaptive controller block is proposed in this paper (see Fig. 2). By inserting adaptive filtering between the inputs and outputs of the inverters, the transfer function of the inverter is first detected. Then, based on the known transfer function of the inverter and the desired output, using inverse filtering, an excitation PWM signal is generated. By introducing a feedback control loop, PWM waveform effectively tracks and compensates load variation and/or grid power disturbance. In this way, the output signal of the inverter is continuously adapted to the desired load and/or grid waveform.

The rest of the paper is organized as follows. Section II presents global structures of single-phase grid-connected conventional power system and power system with adaptive control. Detailed description of the proposed adaptive controller with two different processes, adaptive and inverse filtering, is given in Section III. Simulation results which relate to the generation of an input excitation signal based on the desired output signal are given in Section IV. Section V deals with conclusions.

II. POWER SYSTEM

General structure of the power system based on DC/AC inverter is presented in Fig. 1. It consists of a DC source, an inverter, PWM generator, filter block and a grid utility (or load). The inverter block acts as an interface circuit which connects the DC source to utility grid and/or local load. Primary function of the inverter is to supply active power to the load and grid in accordance with grid connection standards. Grid standards involve numerous requirements, but some of the more representative are the

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following: reactive power compensation, minimization of harmonic distortion produced by nonlinear load, and correct phase synchronism between the current and voltage with aim to achieve unit power factor [1]. The output voltage and current quality at the inverter output can be improved by using filter block. The most common approach is the use of LC or LCL filter.

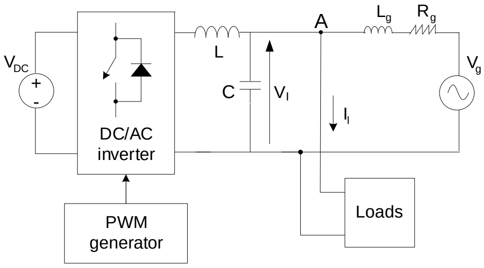


Fig. 1. Power system

PWM generator is implemented in the inverter with order to generate AC waveform of variable voltage and variable frequency. It generates pulses variable duration or duty cycle ratio and, in this way, controls the voltage/current/power at the output of the inverter. The main design challenge now is to obtain an optimal PWM signal for driving the inverter, which should ensure efficient operation and accomplishment of energy quality requirements [4]. The precision of DC/AC conversion depends of applied modulation method and inverter topology [7]. To fulfill the aforementioned requirements we propose adaptive control of the PWM generator block. Architecture of modified conventional power system with adaptive control is presented in Fig. 2. The main goal of this system is that the inverter continuously generates a signal that is consistent with the grid waveform [8].

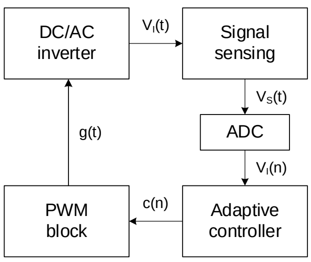


Fig. 2. Power system with adaptive control

As can be seen from Fig. 2, power system with adaptive control has two parts: an analog and a digital part. The digital control, in comparison with the analog control, improves the performance of the DC/AC inverters due to the following reasons: has more flexibility in the designs, the size design is smaller, the algorithms can be easily reprogrammed and improved, it is suitable for the adaptive system [8]. Fig. 2 shows a power system model, which consists of an A/D converter, an adaptive controller, a digital PWM block and a DC/AC inverter block. The A/D converter performs conversion of sensed analog voltage values to digital forms. The PWM block generates the duty ratio signal to control the inverter switches. Proposed adaptive controller is relied upon system identification to identify the parameters of the power inverter, operating under the assumption of certainty equivalence, whereby the estimated inverter parameters are treated as the true values for the purposes of controller design.

III. ADAPTIVE CONTROLLER

Adaptive controller from Fig. 2 consists of two blocks, adaptive filter and inverse filter. These blocks perform two different processes, adaptive and inverse filtering, following each other. First, adaptive filter models the relationship between the excitation and the output signal of the inverter in real time in an iterative manner. Knowledge of the transfer function of the power inverter is required by the controller so that a suitable control signal can be calculated and applied. Based on the transfer function of the inverter and the desired output signal, an appropriate excitation signal can be generated using inverse filtering.

A. Adaptive filtering process

Digital FIR filters are widely employed in practical real-time digital signal processing applications [9, 10]. Whereas any fixed filter is designed in advance with knowledge of the statistics of signals, the adaptive filter continuously adjusts to a changing environment through the use of adaptive algorithms that are needed in order to continuously update the filter coefficients. The adjustable parameters are dependent upon the applications. This paper will focus on applying adaptive filtering in power system identification by using least mean square (LMS) algorithm. An adaptive filter is used to provide a linear model that represents the best fit to an unknown system. In our case, the inverter block presents the unknown system. The system identification procedure has a three-step logic flow: (i) collect input–output data, (ii) choose a model set and (iii) pick the best parameters fit to this model. If the system is dynamic in nature, the model will be time varying.

Fig. 3 shows a MATLAB/Simulink model of adaptive filtering process. A resistor was introduced to simulate the dynamic characteristics of the inverter by changing the load. In order to identify the transfer function of the inverter block, the same input is applied to the inverter and to the adaptive filter. A sample from a digital input signal $x[n]$ is fed into the adaptive filter, that computes a corresponding output signal sample $y[n]$ at time n. This output signal $y[n]$ is computed based on adjustable parameters of the adaptive filter. The output signal is compared to the inverter response signal, $d[n]$, by subtracting the two samples at time n. This difference signal is the error signal, given by $e[n] = d[n] - y[n]$.

The LMS algorithm is used to emulate a desired filter by finding the filter coefficients that relate to producing the least mean squares of the error signal. This algorithm for every input sample first computes the output $y[n]$ using the current set of coefficients $\boldsymbol{h}_n[k]$, then computes the error between the desired response and the filter output, and then updates all the coefficients using the following equation:

$$\boldsymbol{h}_{n+1}[k] = \boldsymbol{h}_n[k] - \mu e[n]x[n-k] \tag{1}$$

The factor μ determines the convergence of the algorithm. Large values of μ result in fast convergence [9].

If perfectly identified, the output $y[n]$ of the adaptive filter should be the same as the output $d[n]$ of the unknown system. However, under realistic environmental conditions (component tolerance, unpredictable load changes, ambient temperature change, ageing effect), the model parameters change so that the obtained coefficient values are not exact but approximate. Our goal is to determine the mathematical form of the transfer function that is closest to the real function of the inverter block. The adaptive filter coefficients, i.e. the transfer function of the inverter block, represent the outcome of the adaptive filtering process.

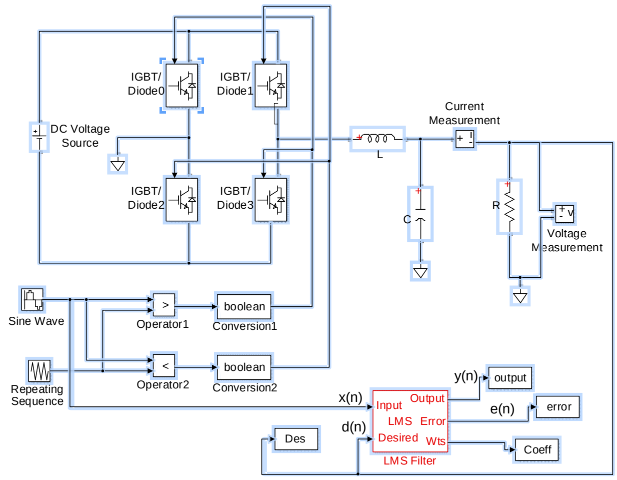


Fig. 3. MATLAB/Simulink model of a power inverter identification by using adaptive LMS filter

B. Inverse filtering process

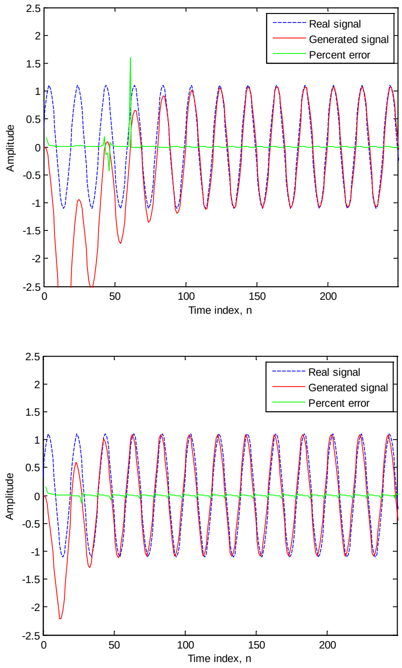
The transfer function of the inverter block is the connection of the output and the input voltage signal and it can be defined as $H(z) = Y(z)/X(z)$. By constantly monitoring the grid voltage, the output signal of the inverter, which should be in accordance with the grid voltage, will be known at all times. Therefore, if the transfer function and the inverter output voltage signal are known, then the input excitation signal can be determined by applying the inverse filtering process.

The pole–zero diagram provides important insight into the properties of systems. To find the poles and zeros of the rational function $H(z)$, we can use MATLAB tool. In the same way, we can find poles and zeros of the inverse function, $H(z)^{-1}$. The system is stable if all poles are inside the unit circle. Therefore, if we have an unstable filter, it is necessary that we first design a stable filter. If any pole outside the unit circle that causes instability is reflected back inside the unit circuit, then the magnitude of the frequency response will remain unchanged. For example, a pole p with $|p| > 1$ is replaced by the new pole $\tilde{p} = 1/p^*$, where $*$ denotes complex conjugation. In addition, a scaling factor is required. The correct scaling is obtained if each factor $(1 - p_i z^{-1})$ with $|p| > 1$ of the inverse function is replaced by $|p|(1 - z^{-1}/p_i^*)$. But the disadvantage of this method is that it will change the phase response. The filtered output signal is delayed with respect to the input signal. The delay caused by the filter equals half the filter order. When the shift is constant, we correct for the delay by shifting the output signal in time. Sometimes the filter delays some frequency components more than others so that a phase distortion occurs. To compensate for this effect, we can perform zero-phase filtering using appropriate function.

IV. Simulation Results

With the aim to demonstrate the validity of the proposed adaptive control, simulation of the power systems is performed using MATLAB/Simulink environment. The performance measures discussed in these simulations are: filter length, convergence rate, error, and stability. The adaptive power system identification is primarily responsible for determining a discrete estimation of the transfer function for an unknown analog system. After a number of iterations of this process are performed, and if the inverter is designed correctly, the adaptive filter's transfer function will converge to, or near to, the unknown inverter block's transfer function. The coeficients of the inverter block are estimated with minimum error. For this configuration, the error signal does not have to go to zero, although convergence to zero is the ideal situation, to closely approximate the given system. There will, however, be a difference between adaptive filter transfer function and the unknown system transfer function if the error is nonzero and the magnitude of that difference will be directly related to the magnitude of the error signal.

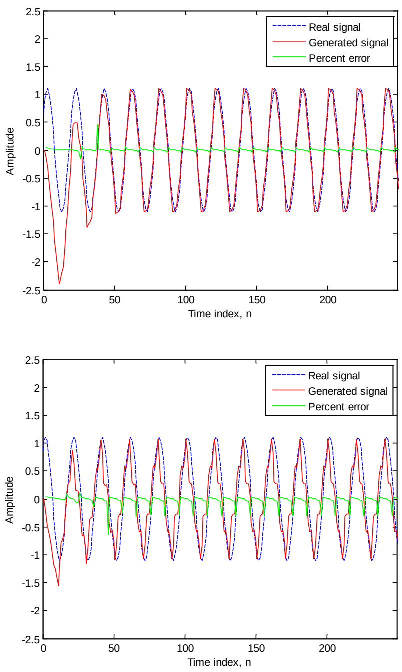
The results of simulation presented in Fig. 4 and 5 show agreement between the real (exact) excitation signal and the new signal obtained by the proposed adaptive method. In addition, in Fig. 4 and 5, the percent error of these two signals is presented. The percent error is chosen instead of an absolute error due to the normalized signal values. Fig. 4 shows the real and the generated signal for different parameters, filter order (N) and convergence factor (μ) where the parameters are: (a) $N = 2$, μ =0.1; and (b) $N = 2$, μ =0.01. As can be seen, faster dynamic response is achieved for a lower value μ. Fig. 5 shows the real and the generated signal for different parameters, where: (a) $N = 4$, μ =0.01; and (b) $N = 6$, μ =0.01. Note that the best design choice of producing inverter excitation signal is achieved by using a lower order filter.



(a)

(b)

Fig. 4. Real and new generated signal for (a) N = 2, μ=0.1, and (b) N = 2, μ=0.01



(a)

(b)

Fig. 5. Real and new generated signal for (a) N = 4, μ=0.01, and (b) N = 6, μ=0.01.

V. CONCLUSION

The adaptive controller of the power system based on LMS algorithm is proposed in this paper. Power inverter identification by using adaptive LMS filter and inverse filtering process are described. The excitation signal of the inverter is generated by the adaptive controller. It is shown that the output signal of the inverter is continuously adapted to the desired load and/or grid signal.

The proposed method can be implemented in other applications where it is necessary to generate an excitation signal based on a known output signal using a system identification method.

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