ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Analysis of an Adaptive Voltage Controller for a Three-Phase PV Inverter in a DG

G. Kusuma
Department of Electrical and Electronics Engineering, Andhra University College of Engineering (A) Visakhapatnam, A.P, India-530003.

T. R. Jyothsna
Department of Electrical and Electronics Engineering, Andhra University College of Engineering (A) Visakhapatnam, A.P, India-530003.

Abstract

This paper presents a robust adaptive voltage control of a three-phase voltage source inverter for a distributed generation system in standalone mode. First, the state-space model of the three phase inverter, which considers the uncertainties of system parameters, is developed. The adaptive voltage control technique that is presented combines an adaption control term and a state feedback control term. The former compensates for system uncertainties, while the latter forces the error dynamics to converge to zero. In addition, the algorithm is robust to system uncertainties and sudden load disturbances. The proposed control strategy guarantees good voltage regulation performance under balanced, and unbalanced loads. The simulation results are presented under the parameter uncertainties and are compared to the performances of the corresponding non-adaptive voltage controller to validate the effectiveness of the proposed control scheme.

Index Terms—***Adaptive voltage control, Distributed Generation system (DGS),Pulse width modulation(PWM), Photo Voltaic (PV).***

INTRODUCTION

The distributed generated systems (DGS) have been vigorously explored in the recent years, due to the increased generation of energy from renewable energy sources using wind turbine, solar cells and fuel cells[1]-[5]. The DGS can accomplish the increase in the demand of electrical power due to increase in the economical standards and also they are environmental friendly. Many forms of DGS are of wind turbine and photovoltaic and these are interfaced to the network through power electronic converters and complex control systems. In some cases the connection to the grid is expensive or impractical. In such cases the DGS units have to operate in parallel [6]-[8] or independently [9]-[10]. In DGS, interface devices make the sources more flexible in their operation and control compared to the conventional electrical machines. However, due to their negligible physical inertia they also make the system potentially susceptible to oscillation resulting from network disturbances. So, in standalone operation the DGS unit is important as the stability of the parallel operation of DGS in which proper load sharing of each unit is one of the main concerns. Since the voltage controller is commonly used in a single DGS unit to multiple DGS unit so a voltage controller design for DGS unit which can grant good stability and voltage regulation under balanced and nonlinear load is an important concern in the DGS control.

For the purpose of improving the quality of inverter output voltage, many researchers are working on designing the controllers for dc–ac power converters.Recently, an adaptive control method [11] has been widely considered in the standalone DGS or UPS voltage control. In [12], an adaptive output voltage controller based on the resonant harmonic filters, is proposed in order to compensate for the unbalance and harmonic distortion on the load. The adaptation law is also included to cope with the uncertainties in the system

Cite this article as: G. Kusuma & T. R. Jyothsna, "Analysis of an Adaptive Voltage Controller for a Three-Phase PV Inverter in a DG", International Journal & Magazine of Engineering, Technology, Management and Research, Volume 5 Issue 4, 2018, Page 51-59.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

parameters. However, the information about output voltage THD is not presented so it is not easy to evaluate the quality of the controllers. In [13] and [14], the precise voltage tracking is achieved under distorting loads by using the adaptive control for the output voltage based on the ideas of dissipativity. In this paper, the uncertainties in the system parameters are addressed through the adaptation, and the stability of the system is guaranteed even under system parameter variations. However, the major drawback of these techniques is the computation complexity. In order to reduce this complexity, a certain predefined value for the parameters is required. In [15], an adaptive control method based on the proportional-derivative control technique is presented for a pulse width modulation (PWM) inverter operation [16]-[17] in an islanded DGS. This paper can guarantee good voltage regulation under various operating conditions such as balanced and unbalanced loads.

This paper presents a robust adaptive voltage controller of the three-phase voltage source inverter for a standalone DGS with different types of loads. First, the state-space model of the three-phase inverter is derived. For this model *abc* to *dq* axis is obtained using park's transformation. The uncertainties in the system are considered. The proposed control technique [18]-[19] combines an adaption control part and a state feedback control part. The adaption control part compensates for system uncertainties, whereas the state feedback control part forces the error dynamics to converge exponentially to zero. The proposed control strategy is not only simple, but also insensitive to system uncertainties and load disturbances. To prove the effectiveness of the proposed control technique the system is modelled in MATLAB and the corresponding results are presented.

INVERTER MODEL AND CONTROL STRATEGY

PV Inverter Modeling

The schematic block diagram shown in Fig. 1, is of a standalone DGS. Here, the energy source we consider is a PV system. The block diagram shows the components/blocks of the DGS, those are the energy source i.e., the PV cells, DC to AC converter, three phase inverter, output filter, isolation transformer and load. The block diagram remains the same for the other energy sources like wind, fuel cells etc. Depending on the type of source the converter configuration will change. In the present work, the PV cells and the DC to DC converter can be replaced by rigid DC voltage source (V_{dc}). In this paper the main objective is to make the system robust with respect to the load side (i.e., different types of loads like balanced and unbalanced loads). This is acceptable because the converter can rapidly recover the reduced dc-link voltage when a heavy load is suddenly applied. Here the isolation transformer is also not used in order to reduce the cost and size of the system, as the voltage needed by the customer is low voltage source which in case of DGS can be generated without any transformer.

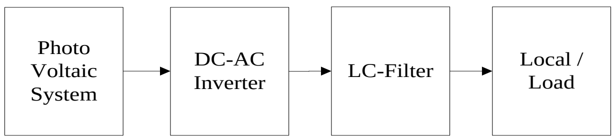


Fig. 1. Schematic Block Diagram of DGS.

The schematic diagram shown in Fig. 2 is of a three phase ac inverter with V_{dc} as input, and an output *LC* filter connected to load. The inverter is a three phase inverter with six gating pulses $S_1$to S_6 and the output filter *L* and *C* connected to load *R*. The *LC* output filter eliminates the harmonic components due to high frequency switching action.

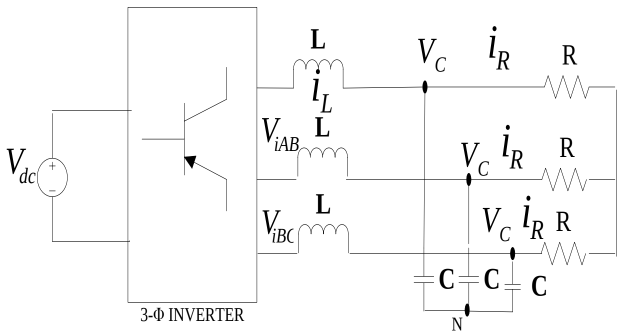


Fig. 2 .Schematic diagram of a three-phase inverter with an *LC* filter in a PV standalone application.

Applying *KCL* and *KVL* for the circuit shown in Fig. 2. we can write the following state equations.

$$\left.\begin{aligned} \frac{dV_C}{dt} &= \frac{1}{C}i_L - \frac{1}{C}i_R \\ \frac{di_L}{dt} &= -\frac{1}{L}V_C + T_i\frac{1}{L}V_i \end{aligned}\right\} \quad (1)$$

where $T_i = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix}$

Transforming the above state equation (1) which is in the stationary *abc* reference frame into synchronous rotating *d-q* reference frame.

$$\begin{aligned} \dot{V}_{Cd} &= \omega V_{Cq} + \frac{1}{C}i_{Ld} - \frac{1}{C}i_{Rd} \\ \dot{V}_{Cq} &= -\omega V_{Cd} + \frac{1}{C}i_{Lq} - \frac{1}{C}i_{Rq} \\ \dot{i}_{Ld} &= \omega i_{Lq} - \frac{1}{L}V_{Cd} + \frac{1}{2L}V_{id} + \frac{1}{2\sqrt{3}L}V_{iq} \\ \dot{i}_{Lq} &= -\omega i_{Ld} - \frac{1}{L}V_{Cq} - \frac{1}{2\sqrt{3}L}V_{id} + \frac{1}{2L}V_{iq} \end{aligned} \quad (2)$$

where $\omega=2\pi f$ which is the angular frequency and f is the fundamental frequency. Here

$k_1 = \frac{1}{C}$; $k_2 = \frac{1}{L}$; $k_3 = \frac{1}{2L}$ & $k_3 = \frac{1}{2\sqrt{3}L}$ and

rewriting the equation (2).

$$\left.\begin{aligned} \dot{V}_{Cd} &= \omega V_{Cq} + k_1 i_{Ld} - k_1 i_{Rd} \\ \dot{V}_{Cq} &= -\omega V_{Cd} + k_1 i_{Lq} - k_1 i_{Rq} \\ \dot{i}_{Ld} &= \omega i_{Lq} - k_2 V_{Cd} + k_3 V_{id} + k_4 V_{iq} \\ \dot{i}_{Lq} &= -\omega i_{Ld} - k_2 V_{Cq} - k_4 V_{id} + k_3 V_{iq} \end{aligned}\right\} \quad (3)$$

For the design of an adaptive voltage control the following assumption are used

1. V_{cqr} and V_{cdr} which are the desired *d-q* reference load voltages are considered as constant for a small sampling period.
2. i_{Rd} and i_{Rq} vary slowly during a small sampling period as in [20].

The reference values of i^*_{Ldr} & i^*_{Lqr} of inverter currents i_{Ld} & i_{Lq} in d-q axis as

$$i^*_{Ldr} = i_{Rd} - \frac{1}{k_1}\omega V_{Cqr} \quad ; \quad i^*_{Lqr} = i_{Rq} - \frac{1}{k_1}\omega V_{Cdr}$$

(4)

The minimum allowable values as in [21] of the inverter *d-q* axis currents references are

$$i_{Ld(q)r} = \left\{\begin{array}{ll} i^*_{Ld(q)r} & if\left|I^*_{Ld(q)r}\right| \le I_{\max} \\ \dfrac{i^*_{Ld(q)r}}{\left|i^*_{Ld(q)r}\right|} I_{\max} & f\left|I^*_{Ld(q)r}\right| > I_{\max} \end{array}\right\} \quad (5)$$

where I_{max} is the maximum allowable magnitude of inverter currents.

The output capacitance C satisfies $0<C<<1$ i.e., $1<<k_1<\infty$ so we can assume that $1<<k_1 +|\Delta k_1|<\infty$. which leads to the following equations.

$$\left.\begin{aligned} i^*_{Ldr} &= i_{Rd} - \frac{1}{k_1}\omega V_{Cqr} \approx i_{Rd} - \frac{1}{k_1 + |\Delta k_1|}\omega V_{Cqr} \\ i^*_{Lqr} &= i_{Rq} - \frac{1}{k_1}\omega V_{Cdr} \approx i_{Rq} - \frac{1}{k_1 + |\Delta k_1|}\omega V_{Cdr} \end{aligned}\right\} \quad (6)$$

where Δk_1 represents the imprecision of the parameter k_1. From equations (1) & (2) following state variables are defined.

$$\begin{aligned} x_1 &= V_{Cd} - V_{Cdr} \quad , \quad x_2 = V_{Cq} - V_{Cqr} \\ x_3 &= i_{Ld} - i_{Ldr} \quad , \quad x_4 = i_{Lq} - i_{Lqr} \end{aligned} \quad (7)$$

From equation (6) the state model of the system represented in equation (3) can be rewritten as

$$\left.\begin{aligned} \dot{x}_1 &= \omega x_2 + k_1 x_3 \\ \dot{x}_2 &= -\omega x_1 + k_1 x_4 \\ \dot{x}_3 &= \omega i_{Lq} - k_2 V_{Cd} + k_3 V_{id} + k_4 V_{iq} \\ \dot{x}_4 &= -\omega i_{Ld} - k_2 V_{Cq} - k_4 V_{id} + k_3 V_{iq} \end{aligned}\right\}$$

(8)

Considering equation (4) and considering the uncertainties of the system the state model in equation (7) can be rewritten as

$$\begin{aligned} \dot{x}_1 &= \omega x_2 + k_1 x_3 + \Delta k_1 x_3 \\ \dot{x}_2 &= -\omega x_1 + k_1 x_4 + \Delta k_1 x_4 \\ \dot{x}_3 &= \omega i_{Lq} - (k_2 + \Delta k_2)V_{Cd} + (k_3 + \Delta k_3)V_{id} + (k_4 + \Delta k_4)V_{iq} \\ \dot{x}_4 &= -\omega i_{Ld} - (k_2 + \Delta k_2)V_{Cq} - (k_4 + \Delta k_4)V_{id} + (k_3 + \Delta k_3)V_{iq} \end{aligned} \quad (9)$$

where Δk_1, Δk_2, Δk_3 & Δk_4 are the uncertainties of the system parameters.

Design of Adaptive Voltage CONTROLLER FOR THE PV INVERTER

The control inputs V_{id} & V_{iq} are divided in to two control components

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

$$\left.\begin{aligned} V_{id} &= V_{id1} + V_{id2} \\ V_{iq} &= V_{iq1} + V_{iq2} \end{aligned}\right\} \quad (10)$$

where V_{id1} & V_{iq1} are the feedback control components, which stabilizes the error dynamics of the system where V_{id2} & V_{iq2} are the nonlinear compensating components. Where V_{id2} & V_{iq2} are given by

$$\begin{aligned} V_{id2} &= \frac{-k_4\omega i_{Ld} - k_3\omega i_{Lq}}{k_3^2 + k_4^2} \\ V_{iq2} &= \frac{-k_4\omega i_{Lq} + k_3\omega i_{Ld}}{k_3^2 + k_4^2} \end{aligned} \quad (11)$$

From equation (9) & (10) the system model equations (8) can be modified as

$$\left.\begin{aligned} \dot{x}_1 &= \omega x_2 + k_1x_3 + \Delta k_1 x_3 \\ \dot{x}_2 &= -\omega x_1 + k_1 x_4 + \Delta k_1 x_4 \\ \dot{x}_3 &= -(k_2 + \Delta k_2)V_{Cd} + k_3V_{id1} + \Delta k_3 V_{id} + k_4 V_{iq1} + \Delta k_4 V_{iq} \\ \dot{x}_4 &= -(k_2 + \Delta k_2)V_{Cq} - k_4V_{id1} - \Delta k_4 V_{id} + k_3 V_{iq1} + \Delta k_3 V_{iq} \end{aligned}\right\} \quad (12)$$

Now assume two functions as

$$\left.\begin{aligned} f_1(x,t) &= a_1 V_{id} + a_2 V_{iq} + a_3 V_{Cd} \\ f_2(x,t) &= a_4 V_{id} + a_5 V_{iq} + a_6 V_{Cq} \end{aligned}\right\} \quad (13)$$

where a_1 ,a_2 ,a_3 ,a_4, a_5 & a_6 are unknown constants.

Considering equation (12) & (13), equation (12) can be rewritten as

$$\left.\begin{aligned} \dot{x}_1 &= \omega x_2 + k_1x_3 + \Delta k_1 x_3 \\ \dot{x}_2 &= -\omega x_1 + k_1 x_4 + \Delta k_1 x_4 \\ \dot{x}_3 &= k_3V_{id1} + k_4V_{iq1} - k_3 f_1(x,t) - k_4 f_2(x,t) \\ \dot{x}_4 &= -k_4V_{id1} + k_3V_{iq1} + k_4 f_1(x,t) - k_3 f_2(x,t) \end{aligned}\right\} \quad (14)$$

where a_1 ,a_2 ,a_3 ,a_4, a_5 & a_6 are equal to

$$\begin{aligned} a_1 &= a_5 = -\frac{k_3\Delta k_3 + k_4 \Delta k_4}{k_3^2 + k_4^2} \\ a_2 &= -a_4 = \frac{k_4\Delta k_3 - k_3\Delta k_4}{k_3^2 + k_4^2} \\ a_3 &= a_6 = \frac{(k_2 + \Delta k_2)}{k_2} \end{aligned} \quad (15)$$

Equation (15) can be represented in state space form as

$$\dot{x} = (A + \Delta A)x + B[u - f(x,t)] \quad (16)$$

where $f(x,t)=[f_1(x,t)\ \ f_2(x,t)]^T= W\Pi^*$

$$A = \begin{bmatrix} 0 & \omega & k_1 & 0 \\ -\omega & 0 & 0 & k_1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \Delta A = \begin{bmatrix} 0 & 0 & \Delta k_1 & 0 \\ 0 & 0 & 0 & \Delta k_1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} = E\,F\,\Delta k_1$$

$$B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ k_3 & k_4 \\ -k_4 & k_3 \end{bmatrix} \quad E = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \quad F = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

$$u = \begin{bmatrix} V_{id1} \\ V_{iq1} \end{bmatrix} \quad W = \begin{bmatrix} V_{id} & V_{iq} & V_{ld} \\ V_{iq} & -V_{id} & V_{lq} \end{bmatrix} \quad \Pi^* = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

Now let us assume that there exists $P=R^{4x4}$ a positive definite matrix that the system represented in (15) satisfies the following inequality .

$$(A + \Delta A)^T P + P(A + \Delta A) + Q - 2PBR^{-1}B^T P < 0 \quad (17)$$

Or

$$A^T P + PA - 2PBR^{-1}B^T P + Q + \Delta A^T P + P\Delta A < 0 \quad (18)$$

where $Q = R^{4x4}$ & $R=R^{4x4}$ are positive definite matrices.

Equation (17) can be rewritten and the inequality holds food for some positive ρ

$$A^T P + PA - 2PBR^{-1}B^T P + Q + \rho PEE^T P + \frac{1}{\rho}F^T F\Delta K_1^{\ 2} < 0 \quad (19)$$

where

$$\Delta A^T P + P\Delta A = \Delta k_1 F^T E^T P + \Delta K_1 PEF \le \rho PEE^T P + \frac{1}{\rho}F^T F \Delta K_1^{\ 2}$$

Assume that $|\Delta k_1| \le \zeta$ where ζ is a known positive constant. Equation (18) satisfies the reccati-like inequality has a positive definite solution for $P=R^{4x4}$.

From APPENDIX I the adaptive control law is given by

$u = -Kx + W\Pi$

(20)

where $K=R^{-1}B^TP$ is a gain matrix, Π is the estimated value of Π^*

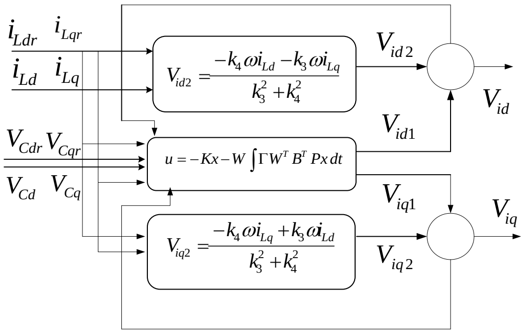


Fig. 3. Schematic diagram of the proposed adaptive voltage controller.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

SIMULATION Results

The DG source modeling and the integration of inverter, grid and load are performed in *abc* as well as the synchronous *dq* reference frames. The simulation results of the proposed voltage controller are obtained using MATLAB under various operating conditions. The results are aimed at exhibiting the behavior of the controller for uncertainties of system parameters as well as load variations which is considered unknown. All the waveforms illustrated in the case studies below represent the Matlab simulation of the control law.

For the purpose of comparison, the nonadaptive voltage controller without adaptive components is executed which is the same as (10) of the proposed controller, and the feedback control law is

$$u = -Kx \qquad (21)$$

where K is the same as in LMI.

$$K = \begin{bmatrix} 1.1787 & -0.6729 & 217.1063 & -125.3464 \\ 0.6729 & 1.1787 & 125.3464 & 217.1063 \end{bmatrix}$$

In the paper, simulations are carried out to verify the effectiveness of the proposed adaptive control algorithm under the following three conditions:

1. Balanced load (0%→100%): The balanced resistive load is instantaneously applied to the inverter output terminals.
2. Balanced load (100% → 0%): The balanced resistive load is instantaneously removed from the inverter output terminals.
3. Unbalanced load: The unbalanced resistive load is connected to the inverter output terminals, i.e., only phase C is opened.

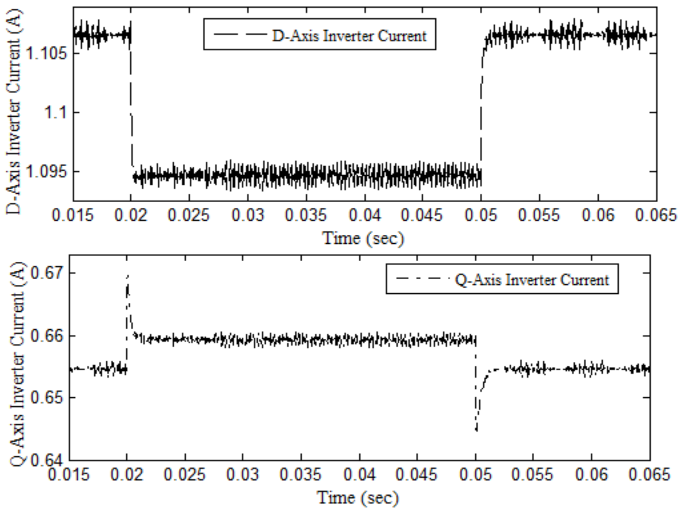
TABLE II
System parameters:

Parameters	Value
DGS power	450VA
R	80Ω
C	6µF
L	6mH
f	60Hz
Dc-link Voltage	280V
Load Voltage	110V(rms)

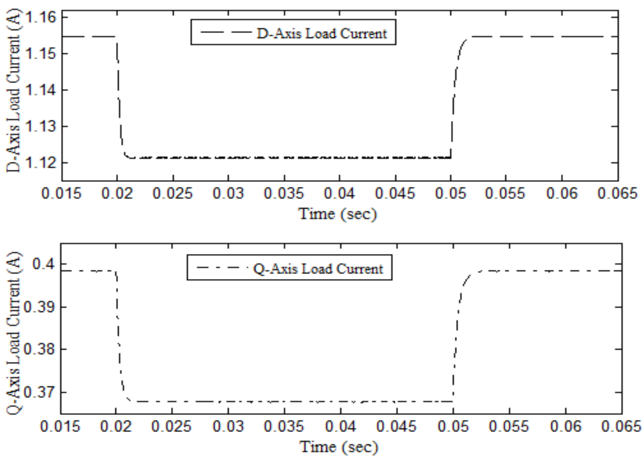
Figs. 4 to 8 shows the simulation results of the proposed adaptive voltage controller using Matlab under three different conditions mentioned previously. Figs. 5 (a) through 5 (c) show the waveforms of load output voltages, load phase currents, and inverter phase currents respectively. In Fig. 6 it is observed that the distortions of the load output voltage waveforms are negligible during the transient when a resistive balanced load is instantaneously applied to or removed from the inverter output terminals (i.e., 0% to 100% or 100% to 0%) because the load voltage waveforms are recovered within a short time of 0.4 ms.

Case Study I: Assessment of Parameter Uncertainty for non-adaptive controller:

Figs. 4(a)-4(c) show the results of inverter current, load current, and capacitor voltages for 150% uncertainties in parameters Δk_1 to Δk_4, between 0.02 to 0.05 seconds for the non adaptive controller.

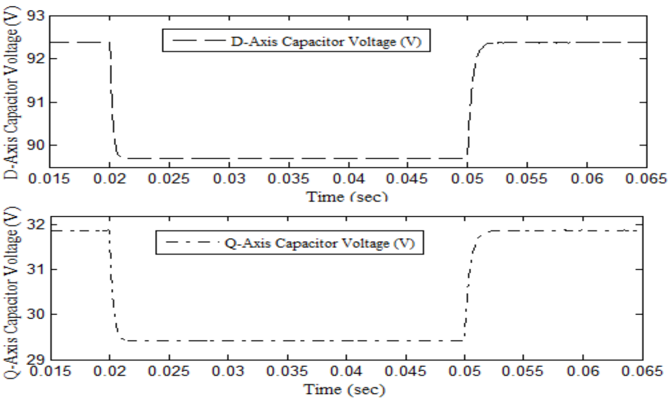


(a)



(b)

ISSN No: 2348-4845
International Journal & Magazine of Engineering,
Technology, Management and Research
A Peer Reviewed Open Access International Journal

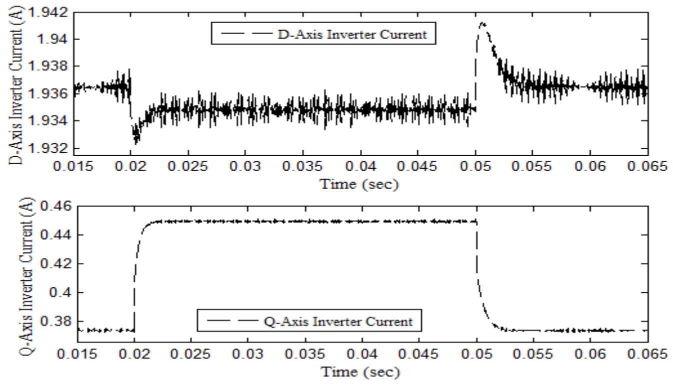


(c)

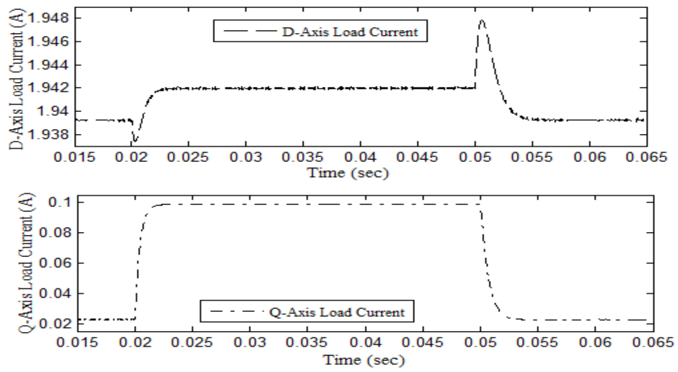
Fig. 4.Simulation results of the nonadaptive voltage controller with 150% uncertainties of system parameters . (a) inverter phase currents ($\mathbf{i}_{Ldq}$). (b) Load phase currents ($\mathbf{i}_{Rdq}$) and Load output voltages ($\mathbf{V}cdq$).

Case Study II: Assessment of Parameter Uncertainty for adaptive controller

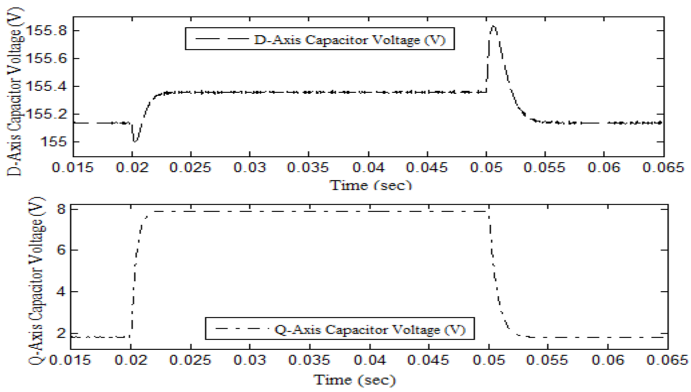
Fig. 5 show the waveforms for the proposed adaptive voltage controller with an uncertainty of 50% for the parameters Δk_1 to Δk_4, under a balanced load of R=80Ω.



(a)



(b)



(c)

Fig. 5.Simulation results of the adaptive voltage controller with 150% uncertainties of system parameters under balanced resistive load (100%-0%).(a) inverter phase currents (i_L). (b) Load phase currents (i_R) and Load output voltages (Vc).

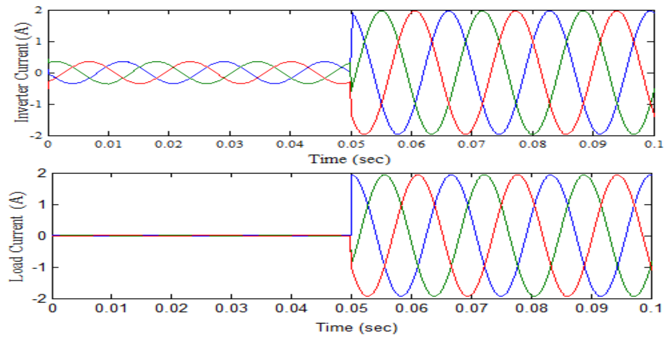


Fig. 6.Simulation results of the adaptive voltage controller with 150% uncertainties of system parameters under balanced resistive load(0%-100%)

Fig. 6, show the waveforms of the proposed adaptive voltage controller with change in balanced load from 0 to 100% from

t = 0sec to t = 0.05sec at an uncertainty of 150% of Δk_1 to Δk_4.

Case Study III: Assessment of Parameter Uncertainty for Adaptive Controller with an Unbalanced Load

Fig. 7 shows the waveforms for the proposed adaptive voltage controller with an uncertainty of 150% for the parameters Δk_1 to Δk_4, under an unbalanced load of R=140Ω.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

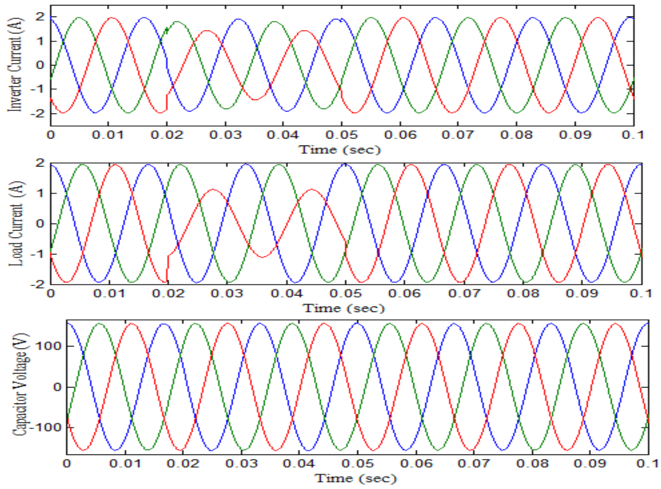


Fig. 7.Simulation results of the adaptive voltage controller with 150% uncertainties of system parameters under unbalanced resistive load in one varaiation. (a) inverter phase currents (i_L). (b) Load phase currents (i_R) and Load output voltages (Vc).

Fig. 8 shows the waveforms for the proposed adaptive voltage controller with an uncertainty of 150% for the parameters Δk_1 to Δk_4, under an unbalanced load from 100% to 0 of R=140Ω.

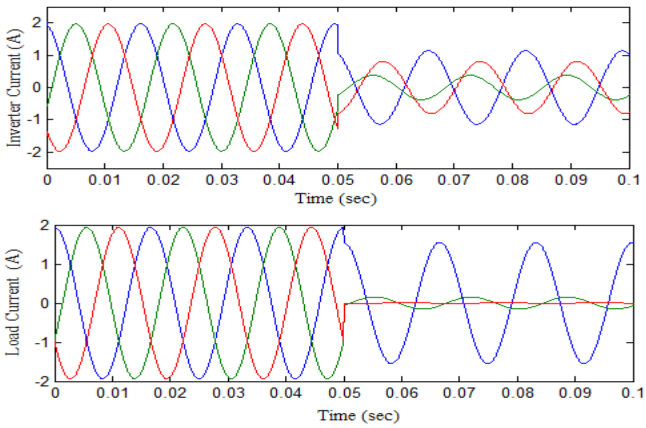


Fig. 8.Simulation results of the adaptive voltage controller with 150% uncertainties of system parameters under unbalanced resistive load.

In all the above simulations, it is observed that there is very slight deviation of system parameters during uncertainties of the system parameters. The system is able to withstand the steady state error, as well as regain the original operating condition, after the uncertainties are removed.

CONCLUSION

In this paper, an adaptive controller for three phase inverter for standalone DGS has been presented using an adaptive control law. Here the proposed controller is easy to implement as well as robust to system uncertainties and sudden load disturbances. In addition, mathematically the stability of the proposed closed-loop control system has been proven. To support the validity of the proposed control algorithm, simulations have been carried out through Matlab software. Finally, the simulation results have shown that the proposed control scheme gives satisfactory voltage regulation performance such as, small steady-state error, fast dynamic behaviour under various loads (balanced load, unbalanced load) in the presence of the uncertainties of system parameters.

APPENDIX I

PROOF OF ADAPTIVE CONTROL LAW

Theorem: Assume that $|\Delta k_1| \le \xi$,for some known positive constant ξ and the Riccati-like inequality (18) is feasible then the controller u can make the error dynamics x converge to zero: $u = -Kx + W\Pi$

where $K=R^{-1}B^TP$ is a gain matrix,

Π is the estimated value of Π^* ,and the adaptive control law is given by $\dot{\Pi} = -\Gamma W^T \sigma$

$\Gamma = diag(\gamma_i); \quad \gamma_i > 0; \; i = 1,2,3.$ and $\sigma = B^T P x.$ (22)

Proof: Let us choose the Lyapunov function as

$V = x^T P x + \Pi_e^T \Gamma^{-1} \Pi_e$

Where $\Pi_e = \Pi - \Pi^*$.Its time derivative along the error dynamics (12)is given by

$$\dot{V} = 2x^T P \dot{x} + 2\Pi_e^T \Gamma^{-1} \dot{\Pi}_e$$

$$= 2x^T P[(A+\Delta A)x + B[u - f(x,t)]] + 2\Pi_e^T \Gamma^{-1}(\dot{\Pi} - \dot{\Pi}^*)$$

where $\sigma^T = x^T P B$

$$= 2x^T P[(A+\Delta A) - BK]x + 2\sigma^T W(\Pi - \Pi^*)] - 2\Pi_e^T W^T \sigma$$

$$= 2x^T P[(A+\Delta A) - BK]x \qquad (23)$$

The Riccati –like inequality (16) implies that

$$\dot{V} < -x^T Q x \le 0. \qquad (24)$$

Then, by integrating both sides of above equation, then we get:

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

$$\int_{0}^{\infty} x(\tau)^T Q x(\tau) = -\int_{0}^{\infty} \dot{V}(\tau) d\tau = V(0) - V(\infty) < \infty. \qquad (25)$$

This implies $x \in L_2 \cap L_\infty, \Pi \in L_\infty$.combining the previous results and using Barbalat's lemma, *x* converges to zero as time goes to infinity, that is,

$$\lim_{t \to \infty} x(t) = 0.$$

(26)

Remark 1: By using the Schur complement formula, it can be shown that the Riccati-like inequality (18) is equivalent to the following linear matrix inequality (LMI).

$$X > 0$$

$$\begin{bmatrix} AX + XA^T - 2BR^{-1}B + \rho EE^T & X & \zeta X F^T \\ X & -Q^{-1} & 0 \\ \zeta F X & 0 & -\rho I \end{bmatrix} < 0.$$

(27)

The solving of the above LMI and setting $P=X^{-1}$, we can obtain the positive definite solution matrix P of (18). A Matlab code to compute the gain K by solving the above LMI.

REFERENCES

[1] M.Liserre,T.Sauter and J.Y.Hung, "Future energy systems:Integrating renewable energy sources into the smart power grid through industrial electronics," IEEE Ind.Electron,Mag.,vol.4,no.1,pp.18-37,Mar.2010.

[2] S. Bogosyan, "Recent advances in renewable energy employment," IEEE Ind. Electron. Mag., vol. 3, no. 3, pp. 54–55, Sep. 2009.

[3] M. Y. Kim, Y. U. Song, and K. H. Kim, "The advanced voltage regulation method for ULTC in distribution systems with DG," J. Elect. Eng.Technol., vol. 8, no. 4, pp. 737–743, Jul. 2013.

[4] A. Q. Huang, M. L. Crow, G. T. Heydt, J. P. Zheng, and S. J. Dale, "The future renewable electric energy delivery and management (FREEDM) system: The energy internet," Proc. IEEE, vol. 99, no. 1, pp. 133–148, Jan. 2011.

[5] A.Mokhtarpour, H. A. Shayanfar, M. Bathaee, and M. R. Banaei, "Control of a single phase unified power quality conditioner-distributed generation based input output feedback linearization," J. Elect. Eng. Technol., vol. 8, no. 6, pp. 1352–1364, Nov. 2013.

[6] M. N. Marwali, J. W. Jung, and A. Keyhani, "Stability analysis of load sharing control for distributed generation systems," IEEE Trans. Energy Convers., vol. 22, no. 3, pp. 737–745, Sep. 2007.

[7] Y. Zhang, M. Yu, F. Liu, and Y. Kang, "Instantaneous current-sharing control strategy for parallel operation of UPS modules using virtual impedance," IEEE Trans. Power Electron., vol. 28, no. 1, pp. 432–440, sJan. 2013.

[8] J. He and Y. W. Li, "An enhanced microgrid load demand sharing strategy,"IEEE Trans. Power Electron., vol. 27, no. 9, pp. 3984–3995, Sep. 2012.

[9] G. K. Kasal and B. Singh, "Voltage and frequency controllers for an asynchronous generator-based isolated wind energy conversion system," IEEE Trans. Energy Convers., vol. 26, no. 2, pp. 402–416, Jun.2011.

[10] H. Nian and R. Zeng, "Improved control strategy for stand-alone distributed generation system under unbalanced and non-linear loads," IET Renew. Power Gener., vol. 5, no. 5, pp. 323–331, Sep. 2011.

[11] H. Karimi, H. Nikkhajoei, and R. Iravani, "Control of an electronicallycoupled distributed resource unit subsequent to an islanding event," IEEE Trans. Power Del., vol. 23, no. 1, pp. 493–501, Jan. 2008.

[12] G. Escobar, P. Mattavelli, A. M. Stankovic, A. A. Valdez, and J. Leyva- Ramos, "An adaptive control for UPS to compensate unbalance and harmonic distortion using a combined capacitor/load current sensing," IEEE Trans. Ind. Electron., vol. 54, no. 2, pp. 839–847, Apr. 2007.

[13] P. Mattavelli, G. Escobar, andA. M. Stankovic, “Dissipativity-based adaptive and robust control of UPS,” IEEE Trans. Ind. Electron., vol. 48, no. 2,pp. 334–343, Apr. 2001.

[14] G. E.Valderrama,A. M. Stankovic, and P.Mattavelli, “Dissipativity-based adaptive and robust control of UPS in unbalanced operation,” IEEE Trans. Power Electron., vol. 18, no. 4, pp. 1056–1062, Jul. 2003.

[15] T. D. Do, V. Q. Leu, Y. S. Choi, H. H. Choi, and J. W. Jung, “An adaptive voltage control strategy of three-phase inverter for stand-alone distributed generation systems,” IEEE Trans. Ind. Electron., vol. 60, no. 12, pp. 5660–5672, Dec. 2013.

[16] A. Yazdani, “Control of an islanded distributed energy resource unit with load compensating feed-forward,” in Proc. IEEE Power Eng. Soc. Gen.Meet., Pittsburgh, PA, USA, Jul. 2008, pp. 1–7.

[17] S. Dasgupta, S. K. Sahoo, and S. K. Panda, “Single-phase inverter control techniques for interfacing renewable energy sources with microgrid—Part I: Parallel-connected inverter topology with active and reactive power flow control along with grid current shaping,” IEEE Trans. Power Electron., vol. 26, no. 3, pp. 717–731, Mar. 2011.

[18] M. Dai, M. N. Marwali, J. W. Jung, and A. Keyhani, “A three-phase four wire inverter control technique for a single distributed generation unit in island mode,” IEEE Trans. Power Electron., vol. 23, no. 1, pp. 322–331,Jan. 2008.

[19] M. Prodanovic and T. C. Green, “Control and filter design of three-phase inverters for high power quality grid connection,” IEEE Trans. Power Electron., vol. 18, no. 1, pp. 373–380, Jan. 2003.

[20] P. Cortes, G. Ortiz, J. I. Yuz, J. Rodriguez, S. Vazquez, and L. G. Franquelo, “Model predictive control of an inverter with output LC filter for UPS applications,” IEEE Trans. Ind. Electron., vol. 56, no. 6, pp. 1875–1883, Jun. 2009.

[21] M. N. Marwali and A. Keyhani, “Control of distributed generation system—Part I: Voltages and currents control,” IEEE Trans. Power Electron., vol. 19, no. 6, pp. 1541–1550, Nov. 2004