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Stand-Alone Wind Power Generation using Adaline Based Integrated Electronic Load Controller

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Abstract
Wind power is clean, economical and environmentally friendly. It is promising alternative electric power generation source at the time of unavailability of fossil fuel and reduces concern over the harmful effects of climate change due to excessive pollution caused by use of fossil fuels. This paper proposes the adaptive linear element (adaline) algorithm based integrated electronic load controller for an isolated windturbine-driven power generation. The adaline extracts the fundamental component of load current to control the voltage and frequency of generator with balancing loads in an integrated manner. The IELC is realized using zigzag/three single-phase transformers and a six-leg insulated-gate bipolar-transistor-based current controlled voltage-source converter, a chopper switch, and an auxiliary load on its dc bus. The generating system is modeled and simulated in MATLAB environment using Simulink and Simpower System toolboxes.
Keywords: Integrated Electronic Load Controller (IELC), Voltage and Frequency Control, Adaptive linear element (ADALINE), Wind Turbine, Wind Power, Wind Farm (WF).

1. INTRODUCTION

Wind energy is renewable way of generating electricity. Due to difference in temperature and pressure, areas known as anticyclones and depressions forms, which results into wind currents. As the air move from the area of anticyclones to areas of depression makes stronger the wind. To start the turbine the wind speed required is 10 to 15 kilometers an hour. Fast-moving parts of wind farms experience increased wear and tear, so the speed limit was maintained for financial and safety reasons. The rotor basic speed 12 to 15 rotations per minute is multiplied with internal gearbox to maintain 1,500 rotations per minute, so that the generator can operate effectively. Power electronic converters are use to change the frequency of the current generated by the turbine to interface with the grid frequency (50 Hz in India), while allowing for a variable rotor rotation speed depending on the wind.

The wind turbine employing synchronous generator especially in the event of change in wind speed demands reactive power which supplied by a volt-ampere reactive (VAR) generating unit connected across its terminal, which is generally met by capacitor banks. In stand-alone system the problems related to terminal voltage regulation, frequency under load perturbation and power quality are faced. Therefore, the use of an integrated electronic load controller (IELC) which controls the voltage and frequency in integrated manner. The control strategy is adaptive linear element (adaline) algorithm, which is use to extract positive sequence fundamental frequency component of the load by tracking the unit vectors along with tuning of the weights. Hence the key factor lies in successful functioning of WF which relies upon the system's ability to regulate the voltage. There will be a negative impact on the stability and power quality in the electrical system due to random nature of wind resources resulting into fluctuating electric power. A set of zigzag three single-phase transformers is used to mitigate the zero-sequence currents and triplen harmonics in the primary winding. And its neutral terminal is used for linear and nonlinear unbalanced loads where the neutral currents is compensated in the primary winding of the zigzag/three single-phase transformers, keeping the secondary windings free from zero-sequence currents and triplen-harmonics currents.

2. SYSTEM CONFIGURATION AND BASIC PRINCIPLE

A 3.7 KW wind farm consisting of one Type-4 wind turbine which consist of synchronous generator coonected to diode rectifier, a DC-DC IGBT-based PWM boost converter and a DC/AC IGBT-based PWM converter. The IGBT Voltage source converter (VSC) is represented by equivalent voltage averaged over one cycle of the switching frequency. A similar method is used for DC-DC converter. This model does not represent harmonics, but the dynamics resulting from control system and power system interaction is preserved. The Type-4 technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The wind speed is maintained constant at 15 m/s. The control system of the DC-DC converter is used to maintain the speed. The reactive power produced by the wind turbine is regulated at 0Mvar. For a wind speed of 15m/s the turbine output power is at its rated power, the pitch angle is 8.8 deg and the generator speed.

The basic equations of the control algorithm are as follows

A. In-phase component of reference source currents

$$V_t = \{(2/3)\ (V_a^2+V_b^2+V_c^2)\}^{1/2}$$

Where, V_a, V_b, V_c are the three phase voltages of the wind farm

$u_{ap} = v_a/V_t \quad u_{bp} = v_b/V_t \quad u_{cp} = v_c/V_t$

Where, u_{ap}, u_{bp}, u_{cp} are unit vector in phase

$V_{dcer(n)} = V^*_{dc(n)} - V_{dc(n)}$

Where,

$V^*_{dc(n)}$ is the reference dc voltage

$V_{dc(n)}$ is the sensed dc-link voltage

$W_{loss(n)} = W_{loss(n-1)} + K_{pd}\{V_{deer(n-1)}V_{deer(n-1)}\} + k_{id}\, V_{deer(n)}$

$W_{loos(n)}$ is considered as part of the active-power component of the source current

K_{pd} and K_{id} are the proportional and integral gain constants of the dc-bus PI voltage controller

Therefore, the average weight of the fundamental reference active-power component of the source of the source current

$Wp(n) = \{ W_{loos}(n) + W_{ap}(n) + W_{bp}(n) + W_{cp}(n)\}/3$

The fundamental component of active-power of the load currents is based on least mean square (LMS) algorithm. The weights of the active-power component of the three-phase load current are estimated as

$W_{ap}(n+1) = W_{ap}(n) + \eta\{i_{La}(n)-W_{ap}(n)u_{ap}(n)\}\, u_{ap}(n)$

$W_{bp}(n+1) = W_{bp}(n) + \eta\, \{i_{Lb}(n)-W_{bp}(n)u_{bp}(n)\}\, u_{bp}(n)$

$W_{cp}(n+1) = W_{cp}(n) + \eta\{i_{Lc}(n)u_{cp}(n)\}u_{cp}(n)$

Where η is the convergence

The three phase source currents

$i^*_{sap} = W_p\, u_{ap} \quad i^*_{sbp} = W_p\, u_{bp} \quad i^*_{scp} = W_p\, u_{cp}$

B. Quadrature Components of Reference Source Currents

$u_{aq} = -\, u_{bp}/\sqrt{3} + u_{cp}/\sqrt{3}$

$u_{bq} = \sqrt{3}\, u_{ap}/2 + (u_{bp} - u_{cp})/2\sqrt{3}$

$u_{cq} = -\sqrt{3}\, u_{ap}/2 + (u_{bp} - u_{cp})/2\sqrt{3}$

where, u_{aq}, u_{bq}, u_{cq} are the unit vector along the quadrature axis

The peek vale of the wind farm terminal voltage and its reference value are fed

$V_{er}(n) = V_{tref}(n) - V_t(n)$

Where,

V_{tref} is the reference value

V_{er} is the amplitude of the terminal voltage of wind farm

The constant value of amplitude of the ac terminal voltage

$W_{qv(n)} = W_{qv(n-1)} + k_{pa}\, \{V_{e(n)} - V_{e(n-1)}\} + k_{ia}\, V_{e(n)}$

Where,

K_{pa} and K_{ia} are the proportional and integral gain constants of the PI controller

$V_{e(n)}$ and $V_{e(n-1)}$ are the error in voltages of nth order

$W_{qv(n-1)}$ is the fundamental quadrature component

The weights of the reactive components of the three-phase load currents are estimated as

$W_{aq}(n + 1) = W_{aq}(n) + \eta\, \{i_{La}(n) - W_{aq}(n)u_{aq}(n)\}\, u_{aq}(n)$

$W_{bq}(n+1) = W_{bq}(n) + \eta\, \{i_{Lb}(n) - W_{bq}(n)u_{bq}(n)\}\, u_{bq}(n)$

$W_{cq}(n+1) = W_{cq}(n) + \eta\, \{i_{Lc}(n) - W_{cq}(n)u_{cq}(n)\}\, u_{cq}(n)$

The average weight of fundamental reactive component of the generator current is

$W_q(n) = [W_{qv}(n) - \{W_{aq}(n) + W_{bq}(n) + W_{cq}(n)\}]\, /3$

The three phase fundamental reference inductive nature components of the currents of the wind farm are given as

$i^*_{saq} = W_q u_{aq} \quad i^*_{sbq} = W_q u_{bq} \quad i^*_{scq} = W_q u_{cq}$

C. Reference source currents

The total reference source currents are the sum of the in-phase and the quadrature components of the reference source currents as

$i^*_{sa} = i^*_{saq} + i^*_{sap}$

$i^*_{sb} = i^*_{sbq} + i^*_{sbp}$
$i^*_{sc} = i^*_{scq} + i^*_{scp}$

These reference source currents (i^*_{sa}, i^*_{sb}, and i^*_{sc}) are compared with the sensed source currents (i_{sa}, i_{sb}, and i_{sc}). The current errors are computed as

$i_{saerr} = i^*_{sa} - i_{sa}$
$i_{sberr} = i^*_{sb} - i_{sb}$
$i_{scerr} = i^*_{sc} - i_{sc}$

These currents errors are amplified using the proportional controller by a gain “K” and which is given as

$V_{cca} = K\ i_{saerr}$
$V_{ccb} = K\ i_{sberr}$
$V_{ccc} = K\ i_{scerr}$

These amplified current-error signals (V_{cca}, V_{ccb}, V_{ccc}) are compared with fixed-frequency (10-kHz) triangular wave to generate unipolar PWM switching signals to generate the gating signals for the six-leg VSC (each phase consists of three H-bridge VSCs) of the IELC.

D. Chopper PWM Controller

The frequency error of the IAG voltage is defined as

$f_{er}(n) = f^*(n) - f(n)$

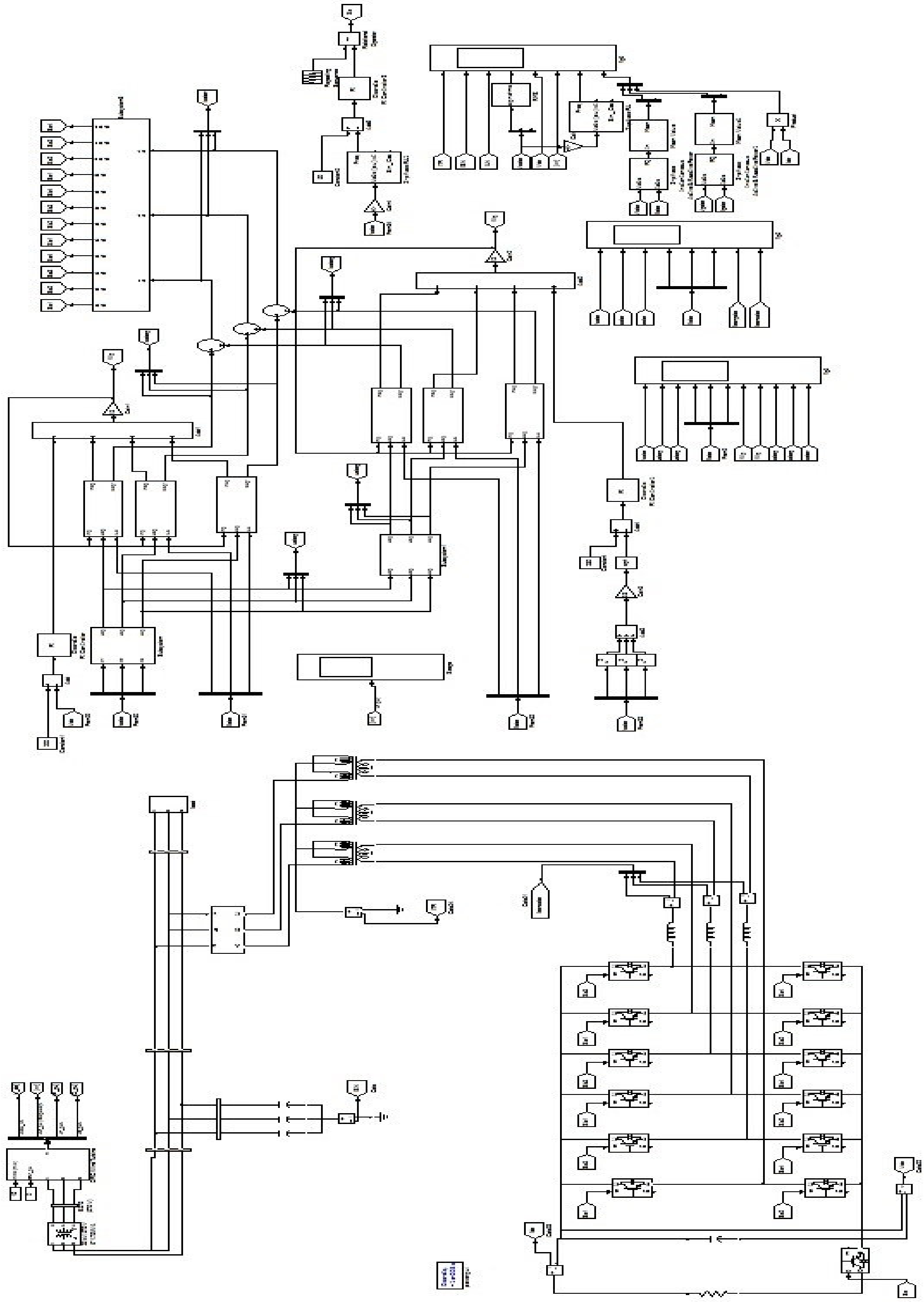
where f* is the reference frequency (50 Hz in the present system) and “f” is the frequency of the voltage of the wind farm.

$V_{cf}(n) = V_{cf}(n-1) + K_{pf}\ \{ f_{re}(n) - f_{re}(n-1) \} + K_{if}\ f_{re}(n)$

This output of the frequency controller Vcf(n) is compared with the fixed-frequency triangular carrier wave (3 kHz in this case) to generate the gating signal of the insulated-gate bipolar transistor (IGBT) of the chopper of IELC.

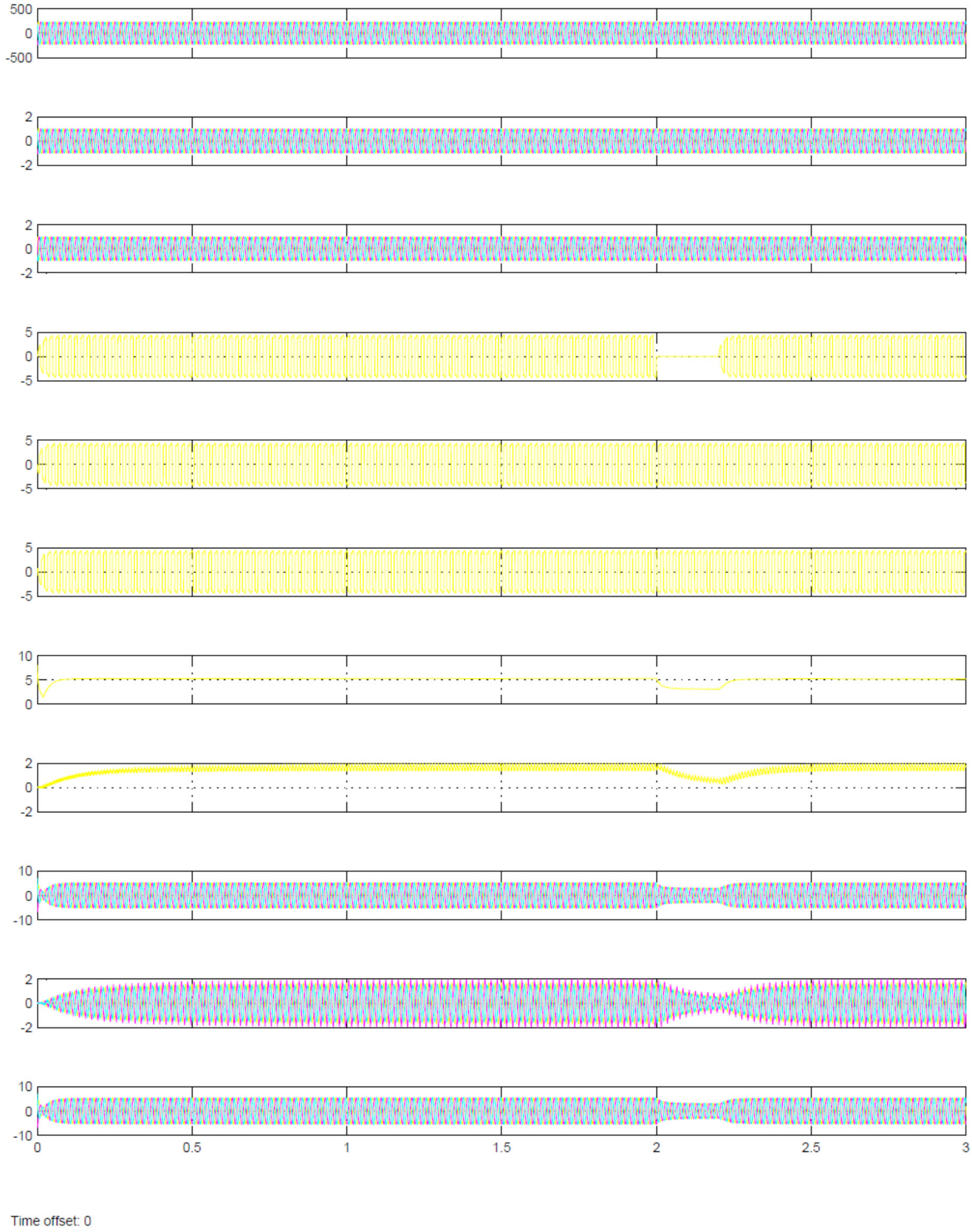
The simulation is carried out in a discrete mode at 10 x 10^{-6} step size with ode23tb solver.

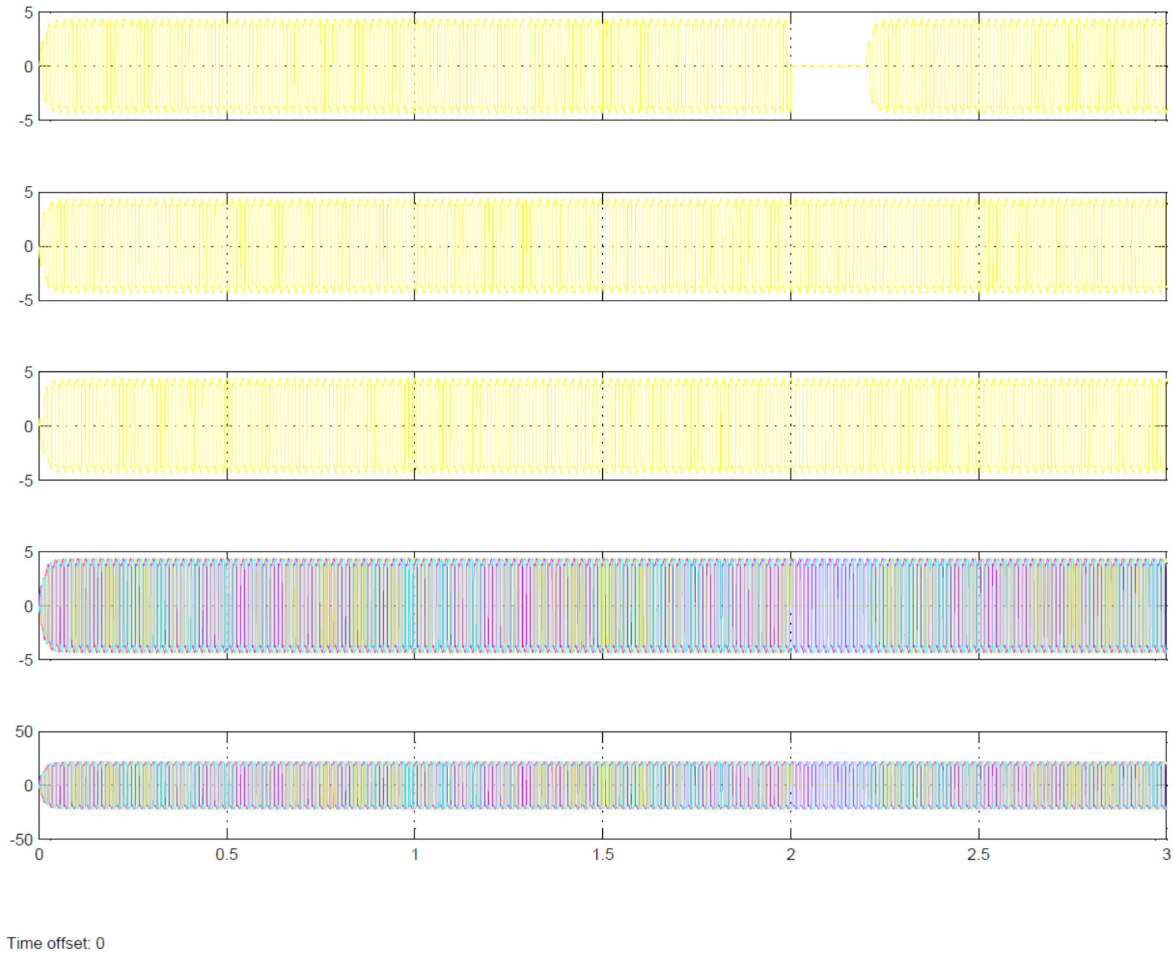
3. MATLAB IMPLEMENTATION



MATLAB diagram of wind farm using ADALINE

4. SIMULATION RESULTS

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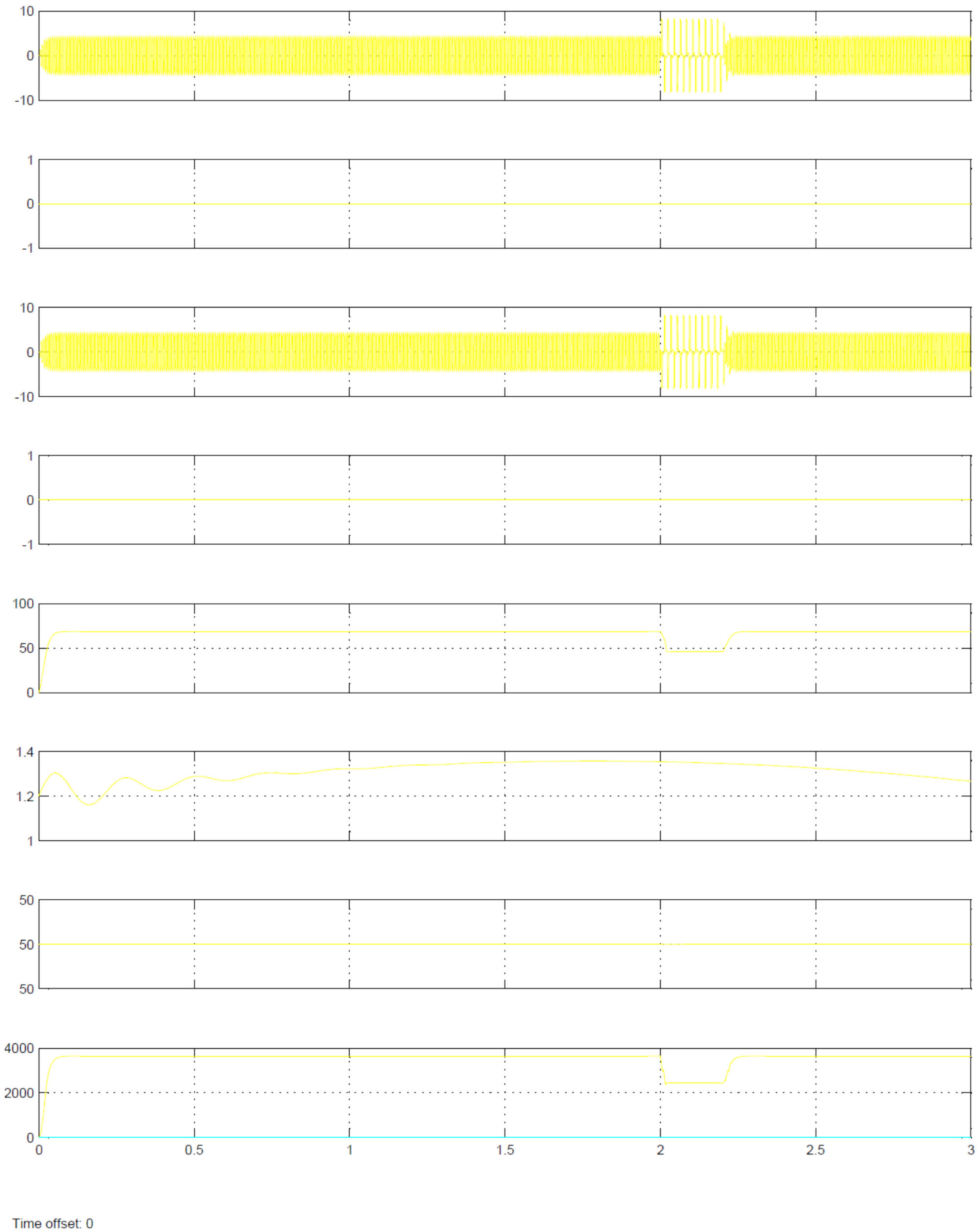
2
2.5
3
Time offset: 0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-1
10
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-1
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1
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50
50
4000
2000
0
0
0.5
1
1.5
2
2.5
3
Time offset: 0

5. CONCLUSION

The stand-alone wind turbine driven generator is simulated with adaline-based control algorithm of an integrated electronic load controller. The IELC based on IGBT has better voltage regulation than thyristors. The capability of the proposed IELC based on adaline control algorithm is studied and observed under different loading condition along with voltage and frequency control, load balancing and harmonic elimination of three phase four wire loads.

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