A Novel Solid State Controller for Parallel Operated Isolated Asynchronous Generators in Pico Hydro Systems

Bhim Singh* and Gaurav Kumar Kasal†

Abstract – This paper deals with a novel solid state controller (NSSC) for parallel operated isolated asynchronous generators (IAG) feeding 3-phase 4-wire loads in constant power applications, such as uncontrolled pico hydro turbines. AC capacitor banks are used to meet the reactive power requirement of asynchronous generators. The proposed NSSC is realized using a set of IGBTs (Insulated gate bipolar junction transistors) based current controlled 4-leg voltage source converter (CC-VSC) and a DC chopper at its DC bus, which keeps the generated voltage and frequency constant in spite of changes in consumer loads. The complete system is modeled in MATLAB along with simulink and PSB (power system block set) toolboxes. The simulated results are presented to demonstrate the capability of isolated generating system consisting of NSSC and parallel operated asynchronous generators driven by uncontrolled pico hydro turbines and feeding 3-phase 4-wire loads.

Keywords: Parallel Operation of IAGs, Novel Solid State Controller, 4-Leg CC-VSC, Isolated Power Generation, Uncontrolled Pico Hydro Turbines

1. Introduction

The development of suitable generators driven by energy sources such as pico hydro, has recently achieved a great significance because of increased emphasis on renewable resources. Asynchronous generators have emerged as a suitable candidate [1] - [7] because of low cost, small size, less weight, robust and brushless construction and self short circuit protection etc. In view of this, these isolated asynchronous generators (IAG) are to be operated in parallel to meet the increased electric load demand in these isolated areas. In comparison to the parallel operation of synchronous generators, asynchronous generators are having number of advantages like there is no need of synchronization between two asynchronous generators, they do not have to run at common synchronous speed, there is no synchronizing torque and no corresponding problems due to hunting and an underground AC cable system could usefully provide part of the required capacitive excitation current. However, only few attempts have been made for the steady state analysis and modeling of parallel operated isolated asynchronous generators [8]-[11]. Therefore, here an attempt is made on a solid state controller for voltage and frequency control of parallel operated IAGs driven by uncontrolled pico hydro turbines feeding three-phase four-wire loads.

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Voltage and frequency regulation of isolated asynchronous generators is the major bottleneck of their commercialization since last two decades and number of attempts have been made for investigating and developing controllers in single phase and three -phase three-wire [12]-[17] applications, however here attempt is made first time to investigate a novel solid state controller (NSSC) for parallel operated isolated asynchronous generators for feeding three-phase four-wire distribution system. It is considered relevant because in remotely located community, most of the loads are single phase loads; hence in place of three-phase three-wire systems three-phase four-wire generating systems are more suitable. In such situations isolated generators feed unbalanced and/or non-linear loads, with a result three-phase terminal voltages and stator currents are also unbalanced and also consist of harmonics. If it is used with neutral wire, three-phase unbalanced currents yield a current in the neutral conductor that involves increased power losses and heating. Therefore, efficient and effective operation of three phase four wire asynchronous generators system with suitable voltage and frequency controller is investigated here, along with neutral current compensation. The novel solid state controller is used with four-leg current controlled voltage source converter (VSC) [18]-[19] for supplying required reactive power and regulating the voltage and frequency in conjunction with DC chopper at its DC bus to regulate the active power.

2. System Configuration

Fig. 1. shows the system configuration of parallel operated

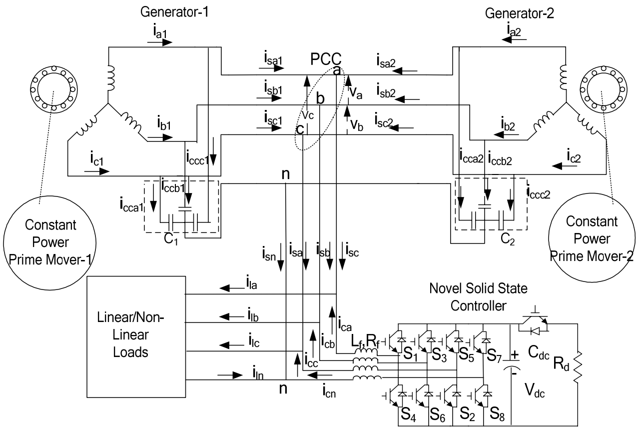

Fig. 1. Schematic diagram of a novel solid state controller for parallel operated asynchronous generators feeding 3-phase 4-wire loads

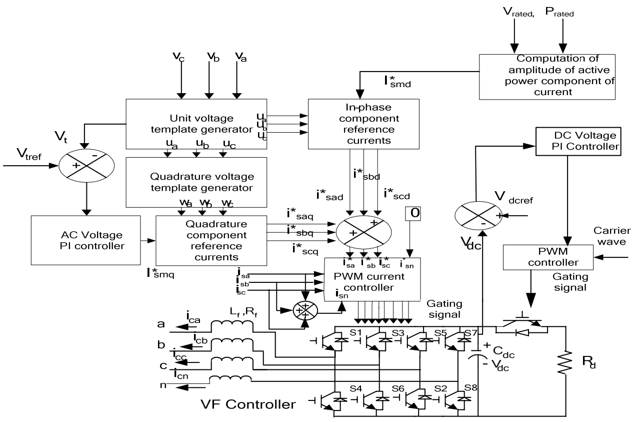

Fig.2. Schematic diagram of control scheme for NSSC

IAGs, with excitation capacitors, a novel solid state controller for voltage and frequency control (consisting 4-leg CC-VSC and DC chopper) and consumer loads. Star connected three-phase capacitor banks with neutral are used for generators excitation and value of excitation capacitors is selected to generate the rated voltage at no load. Constant

power generation of IAGs is maintained by the CC-VSC with self supporting DC bus with chopper and dump load under varying consumer loads. The IAGs generate constant power even when consumer load power changes, the DC chopper of the controller dumps the difference in power (generated – consumed) into dump load. Thus generated voltage and frequency are not affected and remain constant during the change in consumer loads.

The novel solid state controller (NSSC) consists of an IGBT based current controlled 4-leg VSC, DC bus capacitor, DC chopper and AC inductors. The AC output of the VSC is connected through the AC filtering inductors to the common IAGs terminals. The DC bus capacitor is used to filter voltage ripples and provides self-supporting DC bus. The DC chopper is used to control dump power in the controller due to change in consumer loads. The fourth leg of VSC is connected to the star point of 3-phase capacitor banks to form neutral terminal for consumer loads.

Fig. 2. shows the control scheme of NSSC to regulate the voltage and frequency of the asynchronous generators. The control scheme is based on the generation of reference source currents (have two components in-phase and quadrature with AC voltage). The in-phase unity amplitude templates (u_a, u_b and u_c) are three-phase sinusoidal functions, which are derived by dividing the AC voltages v_a, v_b and v_c by their amplitude V_t. Another set of quadrature unity amplitude templates (w_a, w_b and w_c) is sinusoidal function obtained from in-phase vectors (u_a, u_b and u_c). To regulate AC terminal voltage (V_t), it is sensed and compared with the reference voltage (V_{tref}). The voltage error is processed in the PI voltage controller. The output of the PI controller for AC voltage control loop decides the amplitude of reactive current (I_{smq}^*) to be generated by the NSSC. Multiplication of quadrature unity amplitude templates (w_a, w_b and w_c) with the output of PI based AC voltage controller (I_{smq}^*) yields the quadrature component of the reference source currents (i_{saq}*, i_{sbq}* and i_{scq}*). For constant power generation, active power component of source currents are fixed at rated value, which is the amplitude of in-phase component of source current (I_{smd}^*). Multiplication of in-phase unit amplitude templates (u_a, u_b and u_c) with in phase component of source current (I_{smd}^*) yields the in-phase component of the reference source currents (i_{sad}*, i_{sbd}*and i_{scd}*). The sum of instantaneous quadrature and in-phase components of currents is the reference source currents (i_{sa}*, i_{sb}* and i_{sc}*), which are compared with the total sensed source currents (i_{sa}, i_{sb} and i_{sc}). These current error signals are amplified and compared using PWM hystresis controller for generating the PWM signal for switching of the devices of CC-VSC. Fourth leg of VSC is used to compensate the source neutral current (i_{sn})and maintains it at reference value of zero (i^*_{sn}) through switching of this leg of neutral connection. The excess generated power other than consumer loads is dumped in the DC chopper fed dump load resistor (R_d) using DC bus PI voltage controller. The DC bus voltage of VSC of controller is compared with its reference voltage value. The DC bus error voltage is processed in a PI controller. The output of the PI controller is compared with triangular carrier wave to generate gating signal to DC chopper switch (IGBT).

3. Control Algorithm

Basic equations of the control scheme of a proposed controller for parallel operated IAGs is as follows:

3.1 Control for 4-leg CC-VSC

Modeling of the control scheme for a 4-leg voltage source converter for voltage and frequency control along with source neutral current compensation is given as follows:

3.1.1 In phase Component of Reference Source Current

For the constant power application, IAGs should generate constant active power to feed either consumer loads or auxiliary load (R_d). For the constant power, in-phase component of reference source current is set equal to the rated amplitude of active power component of current which is calculated as:

$$I_{smd}^{*} = \sqrt{2}(P_{rated}) / (\sqrt{3}V_{rated}) \quad (1)$$

where P_{rated} is the total generated power of IAGs and V_{rated} is rated voltage at their terminals.

The instantaneous line voltages at the IAGs terminals (v_a, v_b and v_c) are considered sinusoidal and their amplitude is computed as:

$$V_t = \{(2/3)\,(v_a^2 + v_b^2 + v_c^2)\}^{1/2} \quad (2)$$

The unity amplitude templates having instantaneous value in phase with instantaneous voltage (v_a, v_b and v_c), which are derived as:

$$u_a = v_a/V_t\,;\; u_b = v_b/V_t\,;\; u_c = v_c/V_t \quad (3)$$

Instantaneous values of in-phase components of reference source currents are estimated as:

$$i^*_{sad} = I^*_{smd}\, u_a; \quad i^*_{sbd} = I^*_{smd}\, u_b; \; i^*_{scd} = I^*_{smd}\, u_c \quad (4)$$

3.1.2 Quadrature Component of Reference Source Current

The AC voltage error V_{er} at the n^{th} sampling instant is:

$$V_{er(n)} = V_{tref(n)} - V_{t(n)} \quad (5)$$

where $V_{tref(n)}$ is the amplitude of reference AC terminal voltage and $V_{t(n)}$ is the amplitude of the sensed three-phase AC voltage at the IAGs terminals at n^{th} instant. The output of the PI controller ($I^*_{smq(n)}$) for maintaining constant AC terminal voltage at the n^{th} sampling instant is expressed as:

$$I^*_{smq(n)} = I^*_{smq(n-1)} + K_{pa}\,\{V_{er(n)} - V_{er(n-1)}\} + K_{ia}\,V_{er(n)} \quad (6)$$

where K_{pa} and K_{ia} are the proportional and integral gain constants of the proportional integral (PI) controller (values are given in Appendix). $V_{er\,(n)}$ and $V_{er(n-1)}$ are the voltage errors in n^{th} and $(n-1)^{th}$ instant and $I^*_{smq(n-1)}$ is the amplitude of quadrature component of the reference source current at $(n-1)^{th}$ instant.

The instantaneous quadrature components of the reference source currents are estimated as:

$$i^*_{saq} = I^*_{smq}\, w_a;\; i^*_{sbq} = I^*_{smq}\, w_b;\; i^*_{scq} = I^*_{smq}\, w_c \quad (7)$$

where w_a, w_b and w_c are another set of unit vectors having a phase shift of 90º leading the corresponding unit vectors u_a, u_b and u_c which are given as follows:

$$w_a = -u_b / \sqrt{3} + u_c / \sqrt{3} \quad (8)$$

$$w_b = \sqrt{3}\, u_a / 2 + (u_b - u_c) / 2\sqrt{3} \quad (9)$$

$$w_c = -\sqrt{3}\, u_a / 2 + (u_b - u_c) / 2\sqrt{3} \quad (10)$$

3.1.3 Reference Source Current

Total reference source currents are sum of in-phase and quadrature components of the reference source currents as:

$$i^*_{sa} = i^*_{saq} + i^*_{sad} \quad (11)$$

$$i^*_{sb} = i^*_{sbq} + i^*_{sbd} \quad (12)$$

$$i^*_{sc} = i^*_{scq} + i^*_{scd} \quad (13)$$

3.1.4 Neutral Current Compensation

Here fourth leg of the VSC is used to compensate the source neutral current and controls it at reference value (i^*_{sn}). Sensed source neutral current (i_{sn}) is compared with its reference value (i^*_{sn}) and current error signal is amplified and compared using hystresis controller for generating the PWM signal for switching of the fourth leg of the voltage source converter. For making source neutral current (i_{sn}) 'zero' compensating current (i_{cn}) should be equal and opposite in direction of sum of load currents.

$$i_{la} + i_{lb} + i_{lc} = i_{ln} = (-)\, i_{cn} \quad (14)$$

3.1.5 PWM Current Controller

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

$$i_{saerr} = i^*_{sa} - i_{sa} \quad (15)$$

$$i_{sberr} = i^*_{sb} - i_{sb} \quad (16)$$

$$i_{scerr} = i^*_{sc} - i_{sc} \quad (17)$$

$$i_{snerr} = i^*_{sn} - i_{sn} \quad (18)$$

These current errors are fed to PWM current controller (hystresis controller) to generate gating signals for IGBTs.

3.2 Control for DC Bus Chopper

To maintain the DC bus voltage of VSC constant, the DC voltage error $V_{dcer(n)}$ at n^{th} sampling instant ia calculated as:

$$V_{dcer(n)} = V_{dcref(n)} - V_{dc(n)} \quad (19)$$

where $V_{dcref(n)}$ is the reference DC voltage and $V_{dc(n)}$ is the sensed DC link voltage of the CC-VSC. The output of the PI voltage controller at the n^{th} sampling instant is expressed as:

$$V^*_{con(n)} = V^*_{con(n-1)} + K_{pp}\ \{ P_{er(n)} - P_{er(n-1)}\} + K_{pi}\ P_{er(n)} \quad (20)$$

where K_{pp} and K_{pi} are the proportional and integral gain constants of the DC bus voltage controller. The PI controller output ($V^*_{con(n)}$) is compared with the triangular carrier (V_{tri}) waveform and output is fed to the gate of the chopper switch (IGBT) in NSSC.

4. MATLAB Based Modeling

Fig. 3. show the complete MATLAB model of the NSSC and parallel operated asynchronous generators system while Fig. 4.(a)-(d) demonstrate the different subsystems. Main system consists of parallel connected asynchronous machines with separate capacitor bank and NSSC. The modeling of IAGs is carried out using two different asynchronous machines 22kW, 415V, 50Hz, Y connection and 7.5 kW, 415V, 50Hz, Y connection and capacitor banks with neutral. The controller is realized with 4-leg voltage source converter and DC chopper at its DC bus. Both linear and non-linear loads are considered here to demonstrate the capability of controller. Simulation is carried out in discrete mode at 5e-6 step size with ode23tb (stiff/ TR-BDF-2) solver.

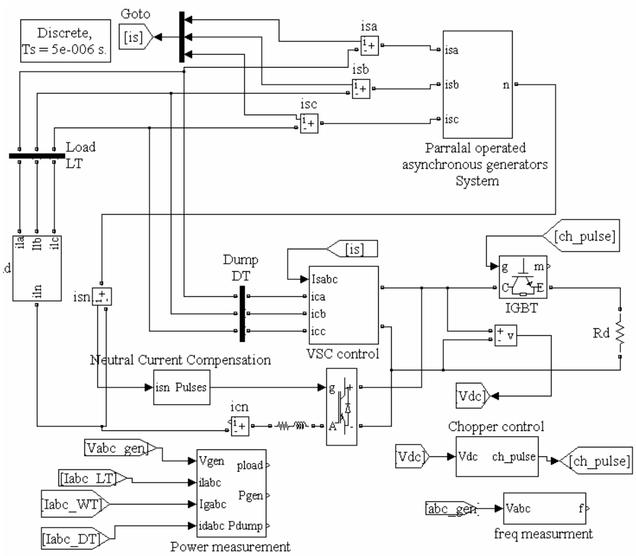

Fig. 3. MATLAB based simulation model of proposed electric system

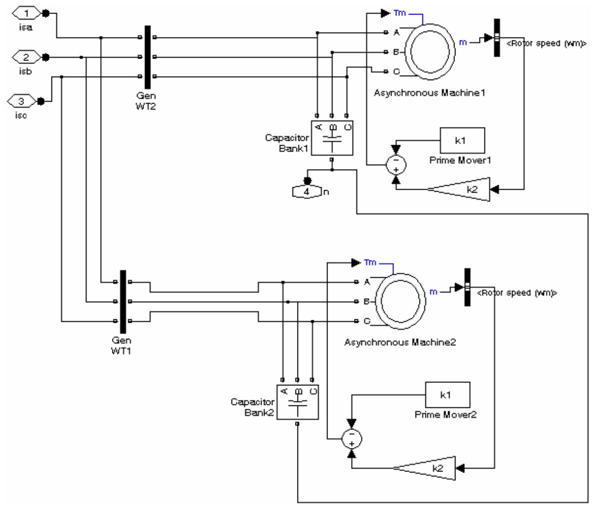

Fig. 4(a). Subsystem of parallel operated isolated asynchronous generators.

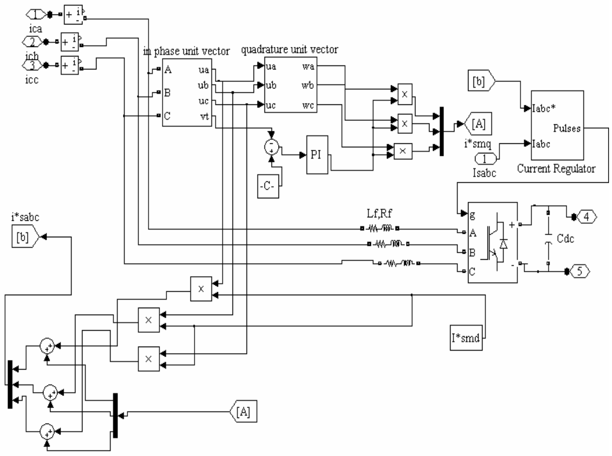

Fig. 4(b). Subsystem of VSC control.

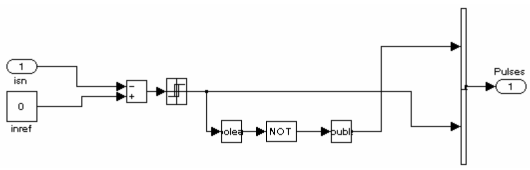

Fig. 4(c). Subsystem of neutral current compensation.

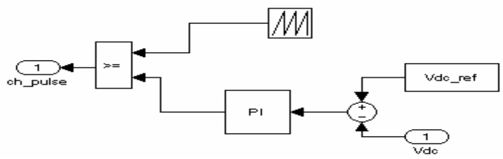

Fig 4(d). Subsystem of chopper control.

5. Results and Discussion

The NSSC for parallel operated IAGs system feeding three-phase four-wire linear/ non- linear, balanced-unbalanced loads are simulated and waveforms of the generator voltage (v_{abc}) and currents (i_{abc1}) and (i_{abc2}), capacitor current (i_{cca1}, i_{cca2}), load current (i_{labc}), controller current (i_{cabc}), neutral current of source(i_{sn}), compensator (i_{cn}), and load (i_{ln}), terminal voltage (V_t), DC link voltage (v_{dc}), frequency (f) and speed of both generators (ω_1 and ω_2) and variation of powers of asynchronous generators(P_{gen1}, P_{gen2}) consumer load (P_{load}) and dump load (P_{dump}) etc are shown in Figs. 5-6. For the simulation, a 7.5 kW, 415V, and 22kW, 415V star connected asynchronous machines have been used as an asynchronous generators and parameters are given in Appendix.

5.1 Performance of IAGs-NSSC System Feeding 3-Phase 4-Wire Linear Loads

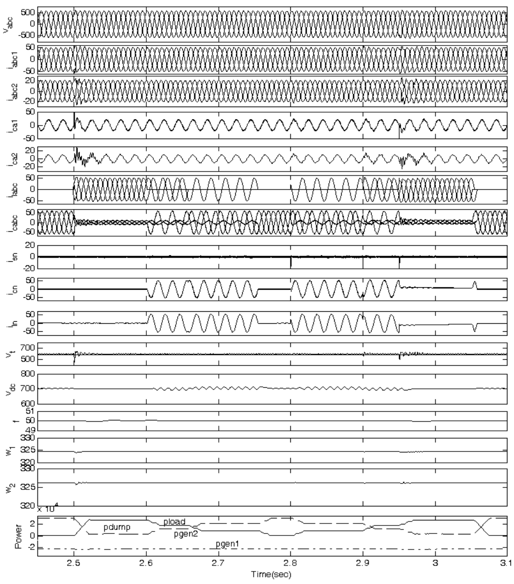

Fig. 5. Transient waveforms of parallel operated IAGs with NSSC feeding 3-phase 4-wire resistive load.

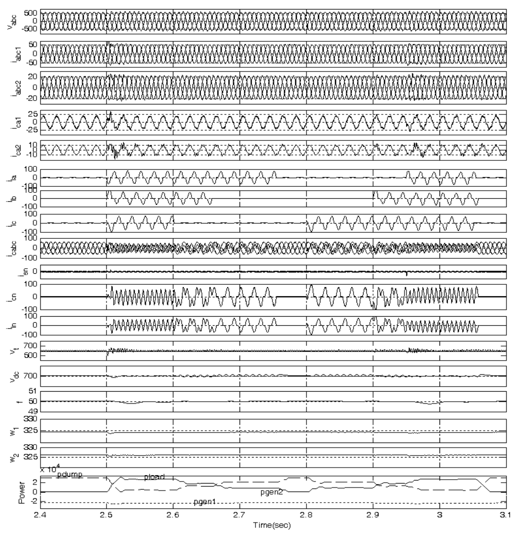

Fig. 6. Transient waveforms of parallel operated IAGs with NSSC feeding 3-phase 4- wire nonlinear loads.

Fig. 5. shows the performance of the NSSC system with balanced/unbalance resistive load. At 2.5 sec balanced three single phase load each of 9.5kW is applied between each phase and neutral then the power is drawn by dump load (P_{dump}) is suddenly reduced to regulate the generators rated power (P_{gen1} and P_{gen2}) which in turn maintain the system.

frequency constant. With opening of single phase load at 2.6 sec and then other phase at 2.65sec the load becomes unbalanced and charging and discharging of DC bus capacitor is observed which shows the load balancing aspect of the controller as well as neutral current flowing through the neutral wire (i_{sn}) is zero. At 2.75 sec the consumer load is fully removed, dump load absorbs the full active power generated by the generators, which shows that controller maintains the generators power and voltage constant.

5.2 Performance of IAGs-NSSC System Feeding 3-Phase 4-Wire Non-linear Loads

Fig. 6. shows the performance of the parallel operated IAGs-NSSC, system with 3-phase 4-wire balanced-unbalanced non-linear loads using single phase diode rectifier with resistive load and capacitor filter at its DC side. At 2.5 sec, a balanced non- linear load is applied then dump power (p_{dump}) is reduced with in a cycle for regulating the power, and controller currents (i_{cabc}) become non-linear for eliminating harmonic currents. During the load unbalancing DC bus capacitor (v_{dc}) charging and discharging is observed same as with linear load and with all these, source neutral current (i_{sn}) is also compensated. Fig. 7 and 8 demonstrate the harmonic spectrum of source voltage (v_a) and current (i_a) with balanced and unbalanced non-linear load respectively. The total harmonic distribution of voltages and currents of IAGs are very small and the NSSC compensates the harmonics of the consumer loads.

6. Conclusions

The simulation results of a novel solid state controller for voltage and frequency control of parallel operated IAGs have demonstrated quite satisfactory operation for feeding 3-phase 4-wire loads. The NSSC-IAGs system is able to feed balanced/unbalanced linear and non-linear loads and it is concluded that the proposed novel solid sate controller (NSSC) is found suitable for voltage and frequency control along with load balancing, neutral current compensation and harmonic elimination of non-linear loads.

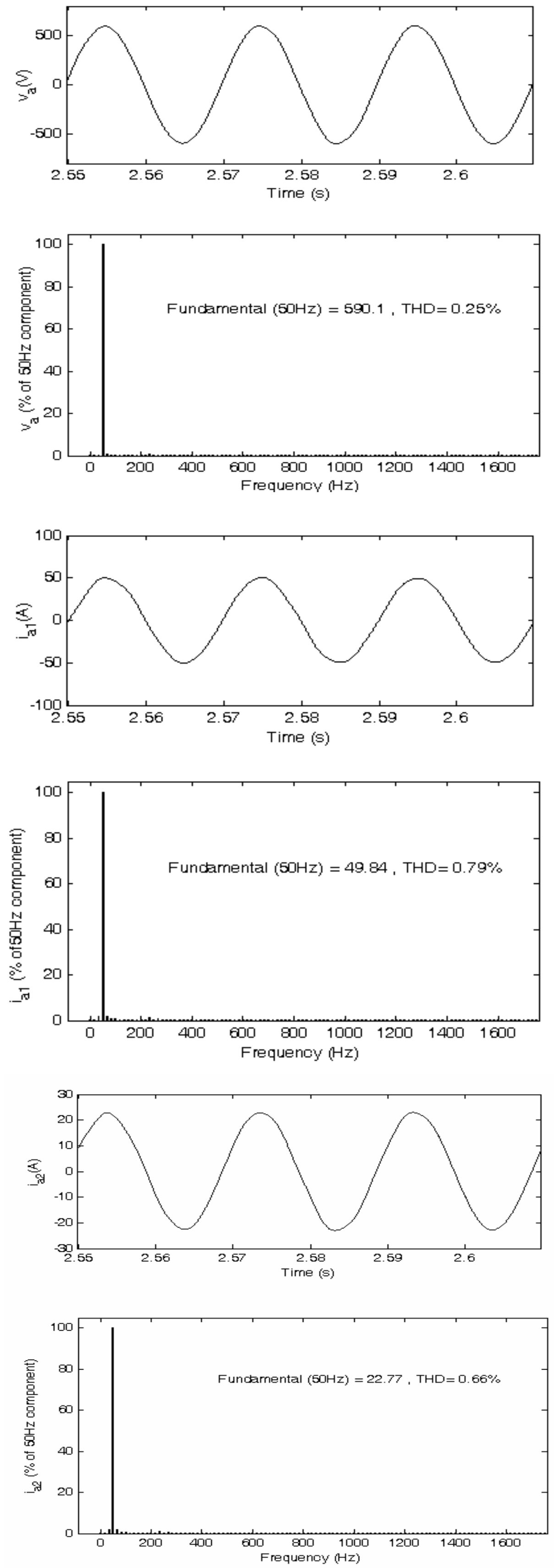

Fig. 7. Harmonic spectrum of source voltage and IAGs currents at balanced loads.

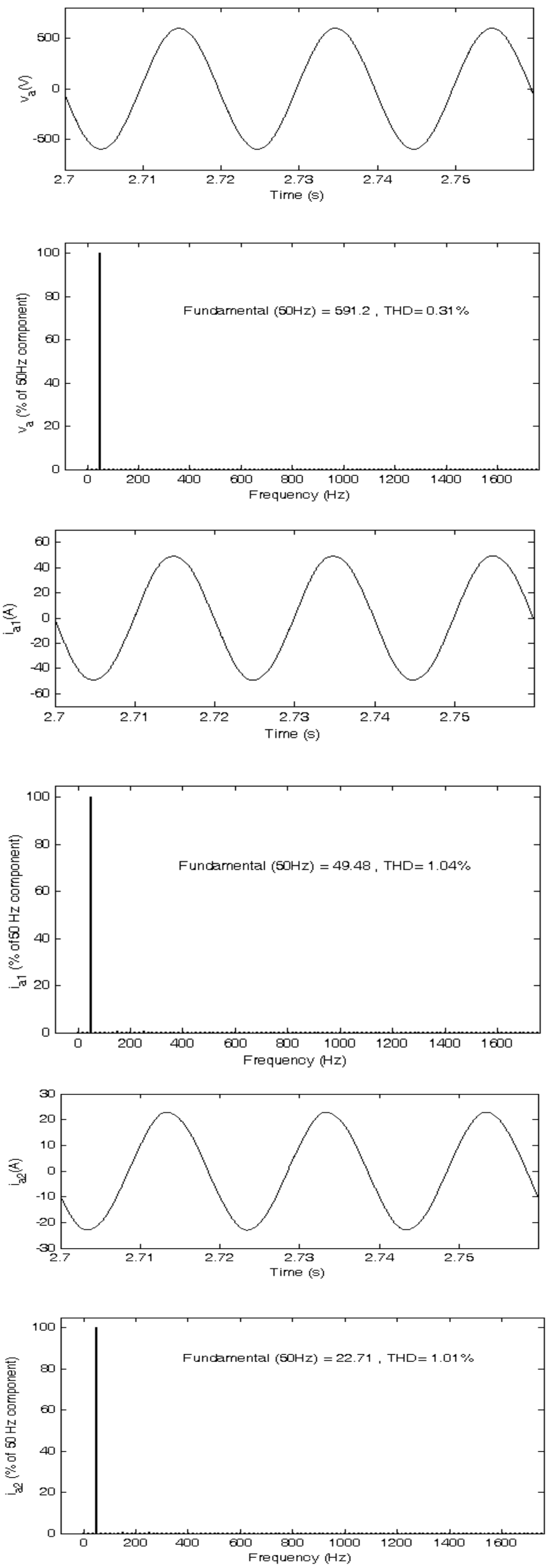

Fig. 8. Harmonic spectrum of source voltage and IAGs currents at unbalanced loads.

Appendix

1. The Parameters of 22kW, 415V, 50Hz, Y-Connected, 4-Pole Asynchronous Machine

$R_s = 0.2511\Omega$, $R_r = 0.2489\Omega$, $X_{lr} = X_{ls} = .52\Omega$, J = 0.304 kg-

$L_m = 0.075$ $\quad I_m<8.0$

$L_m = 0.075-0.003(I_m-8.0)$ $\quad 8<I_m<13$

$L_m = 0.06-0.002(I_m-13)$ $\quad 13<I_m<23$

2. The Parameters of 7.5kW, 415V, 50Hz, Y-Connected, 4-Pole Asynchronous Machine

$R_s = 1\Omega$, $R_r = 0.77\Omega$, $X_{lr} = X_{ls} = 1.5\Omega$, J = 0.1384 kg-m^2,

$L_m = 0.134$ $\quad (I_m<3.16)$

$L_m = 9e\text{-}5I_m^2 - 0.0087I_m + 0.1643$ $\quad (3.16<I_m<12.72)$

$L_m = 0.068$ $\quad (I_m>12.72)$

3. Controller Parameters

$L_f = 4mH$, $R_f = 0.1\Omega$, and $C_{dc} = 4000\mu F$, $R_d = 55\Omega$.

$K_{pa} = 0.8$, $K_{ia} = 0.05$, $K_{pp} = 1.4$, $K_{pi} = 0.004$.

4. Consumer Loads

Resistive load 9.5kW single phase load

Non-linear load - 9.5kW with 1200µF capacitor at DC end of single phase diode rectifier

5. Prime Mover Characteristics for 22kW Machine

$T_{sh} = K1-K2\ \omega r$

$K_1 = 6100$, $K_2 = 36.25$

6. Prime Mover Characteristics for 7.5 kW Machine

$T_{sh} = K_1-K_2\ \omega_r$

$K_1 = 3300$, $K_2 = 10$

References

[1] S.N. Bhadra, D. Kastha, S.Banerjee, "Wind Electrical Systems" 1st Ed. Oxford University Press ,New Delhi 2004.

[2] M. Godoy Simoes, Felix A. Farret, "Renewable Energy Systems" 1st Ed. CRC Press Florida, 2004.

[3] Jean-Marc Chapallaz, Dos Ghali,Peter Eichenberger, Gehard Fischer, "Manual on induction motors used as generators" published by Vieweg Deutsches Zentrum Fur Entwicklingstechnologien-Gmbh, Eschborn, 1992.

[4] B. Singh, "Induction generator –a prospective," Electric Machines Power Systems, vol.23,pp 163-177,1995.

[5] R.C. Bansal, T.S. Bhatti and D.P. Kothari, "Bibliography on the application of induction generator in non conventional energy systems," IEEE Trans. on Energy Conversion, vol. EC-18, no.3, pp.433-439, September 2003.

[6] G.K.Singh, "Self-excited induction generator research- a survey" Electrical Power System Research, vol 69, no. 2-3, pp 107-114, May 2004.

[7] R.C. Bansal, "Three phase self excited induction generators: an overview", IEEE Trans. on Energy Conversion, vol 20, no. 2, pp. 292-299, June 2005.

[8] D. B. Watson and I.P. Milner, "Autonomous and parallel operation of self excited induction generator," International Journal of Electrical Engineering Education, vol. 22, pp. 365-374, 1985.

[9] A.H. Al-Bahrani and N.H. Malik, "Voltage control of parallel operated self excited induction generators," IEEE Trans. Energy Conversion, vol.8, no.2, pp. 236-242, 1993.

[10] A.H. Al-Bahrani and N.H. Malik, "Steady-state analysis of parallel operated self-excited induction generator," IEE Proceedings, Pt. C, vol.140, no.1, pp.49-55, 1993.

[11] Chandan Chakraborty, S.N. Bhadra, Muneaki Ishida and A.K. Chattopadhyay, "Performance of parallel operated self excited induction generators with the variation of machine parameters," in Proc. of IEEE Conference on Power Electronic and Drive Systems, July. 1999, pp. 86-91.

[12] J. M. Elder, J. T. Boys and J. L. Woodward, "Integral cycle control of stand-alone generators," IEE Proc. vol. 132, Pt. C, no. 2, pp. 57-66, March 1985.

[13] R. Bonert and S. Rajakaruna, "Self-excited induction generator with excellent voltage and frequency control," IEE Proc.-Gener. Transm. Distrib., vol. 145, no. 1, pp. 33-39, January 1998.

[14] E. G. Marra and J. A. Pomilio, "Self excited induction generator controlled by a VS-PWM bi-directional converter for rural application," IEEE Trans. on Industry Applications, vol. 35, no. 4, pp. 877-883, July/August 1999.

[15] B.Singh, S.S. Murthy and Sushma Gupta, "An improved electronic load controller for self excited induction generator in micro-hydel applications", in Proc.of IEEE Annual Conference of the Industrial Electronic Society, vol. 3, Nov. 2003, pp. 2741-2746.

[16] B.Singh, S.S. Murthy and Sushma Gupta, "A voltage and frequency controller for self-excited induction generators" Electrical Power Components and Systems, vol., 34, pp 141-157, 2006.

[17] Luiz A.C. Lopes and Rogerio G. Almeida, "Wind-driven induction generator with voltage and

frequency regulated by a reduced rating voltage source inverter" IEEE Trans. on Energy Conversion, vol. 21, no. 2, pp. 297-304, June 2006.
[18] C.A. Quinn and N. Mohan, "Active filtering of harmonic currents in three-phase four wire systems with three-phase and single phase non-linear loads," in Proc. of IEEE APEC92, pp.829-836.
[19] B.Singh, K. Al-Haddad and A. Chandra, "Harmonic elimination, reactive power compensation and load balancing in three-phase four wire electric distribution system supplying non-linear loads," Electric Power Systems Research, vol. 44, pp. 93-100, 1998.

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