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Electronics Based Dump Load Controller (DLC) for an Grid Isolated Asynchronous Generator (GIAG)

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ABSTRACT: In this paper, an electronics based dump load controller (DLC) has been designed and simulated in MATLAB/SIMULINK to regulate voltage and frequency of a GIAG feeding three-phase balanced and unbalanced consumer load for constant power applications such as uncontrolled turbine in Pico hydro power generation (<10kW) has been presented. The DLC consists of a six-pulse diode bridge rectifier, IGBT operated chopper switch, filtering capacitor, PI controller and a resistive Dump load. The implementation of six-pulse DLC is carried out in MATLAB/SIMULINK and Simpower System Blockset. The transient behaviour of GIAG-DLC system is examined and studied under different operating conditions to demonstrate the capabilities of electronics based dump load controller (DLC). The different operating conditions such as switching ON and switching OFF the three-phase balanced consumer load are obtained by introducing circuit breakers in the Simulink model of the system under study.

Key words: Asynchronous Generator, electronic load design, dump load, six-pulse diode bridge rectifier, pi controller, MATLAB

I. INTRODUCTION

Decentralized or stand-alone power generation has attracted attention of researchers in recent years for use in remote and isolated areas due to the reduced amount of energy lost in transmitting electricity, reduced size and number of power lines that must be constructed. Thus, a decentralized power generation system is an alternative or an enhancement of the traditional electric power system. An grid isolated asynchronous generator (GIAG) have received increased attention in recent years due to the suitability of these generators with renewable energy sources e.g. solar, wind, wave and small hydroelectric plants as compared to fossil fuel energy sources. An grid isolated asynchronous generator (GIAG) was preferred over a conventional synchronous generator due to its various advantages: brushless rotor, reduced unit, no separate DC exciter, ruggedness, less initial & maintenance cost, self protection against severe overloads across the load terminals, inherent protection against short-circuits etc. Due to the latest research on non conventional energy sources and grid OFF systems, the GIAG becomes one of the most important and favoured renewable sources of energy [1-8]. For low power rating (less than 100kW) uncontrolled turbines driving Grid Isolated Asynchronous Generator are preferred which maintain the hydropower constant, thus requiring the generator output power to be held constant at varying consumer loads. This requires Electronics based load controller where a dump load is connected in shunt or across the consumer load so that the total power consumed is held constant.

Various types of electronics based DLCs for GIAG have been reported in literature along-with its advantages and disadvantages [4-8]. The GIAG can be used for constant power applications and for constant speed variable power application. In constant power applications, prime mover speed, value of excitation capacitor and the consumer load are kept constant and thus known as a single point operation. In constant speed variable power applications, speed of the prime mover is kept constant but the value of excitation capacitance increases with load. For constant power application, generated power and consumer output power must be fixed for stable operation of three-phase GIAG. Input power remains constant with uncontrolled pico-hydro turbine but output power may not be constant due to varying consumer load. In this paper, a simple electronics based DLC is developed which maintain the GIAG output power constant.

II. SYSTEM CONFIGURATION

A Simulink diagram of the three-phase DLC-GIAG system is depicted in Figure 1. The whole system comprises of a star-connected Asynchronous machine, appropriate value of excitation capacitor to generate the rated voltage at full load, delta-connected three-phase consumer load and electronics based dump load controller (DLC). It consists of six-pulse diode bridge rectifier along with the IGBT operated chopper switch, a filtering capacitor(C), dump load resistance (Rd). The diode bridge rectifier is used to convert three-phase ac terminal voltage of GIAG to dc voltage. The output dc voltage has the ripples, which should be filtered and therefore a filtering capacitor is used to smoothen the dc voltage. An IGBT is used as a chopper switch providing the variable dc voltage across the dump load. Initially the consumer load and the electronics based dump load controller are kept OFF and the generator is self-excited at no-load. After successful voltage build-up, the electronics based dump load controller consumes the whole of the generated power. When both the consumer load and the chopper is switched ON, the current flows through the dump load and consumes the difference between the generated power and consumer load power and this result in a constant load on the GIAG and hence constant voltage and frequency at the balanced consumer load. The duty cycle of the chopper is varied by a discrete PI controller. The output of the PI controller is compared with the saw tooth wave to generate switching signal of varying duty cycle for the chopper switch. According to the principle of operation of the system, the suitable value of capacitors is connected to generate rated voltage at desired power [4-8]. The input power of the GIAG is held constant at varying consumer loads. Thus GIAG supplies power to consumer load and dump load in parallel such that the total power is constant

$$P_{gen} = P_{eload} + P_{cload}$$

Where, P_{gen} is the power generated by the Grid Isolated Asynchronous Generator (GIAG) (which should remain constant). P_{cload} is the consumer power and P_{eload} is the electronic dump load power to be dumped in dump load resistance R_D. The electronic dump load power (P_{eload}) may be used for various applications like water heating, charging of batteries, cooking purpose, baking, space heating etc.

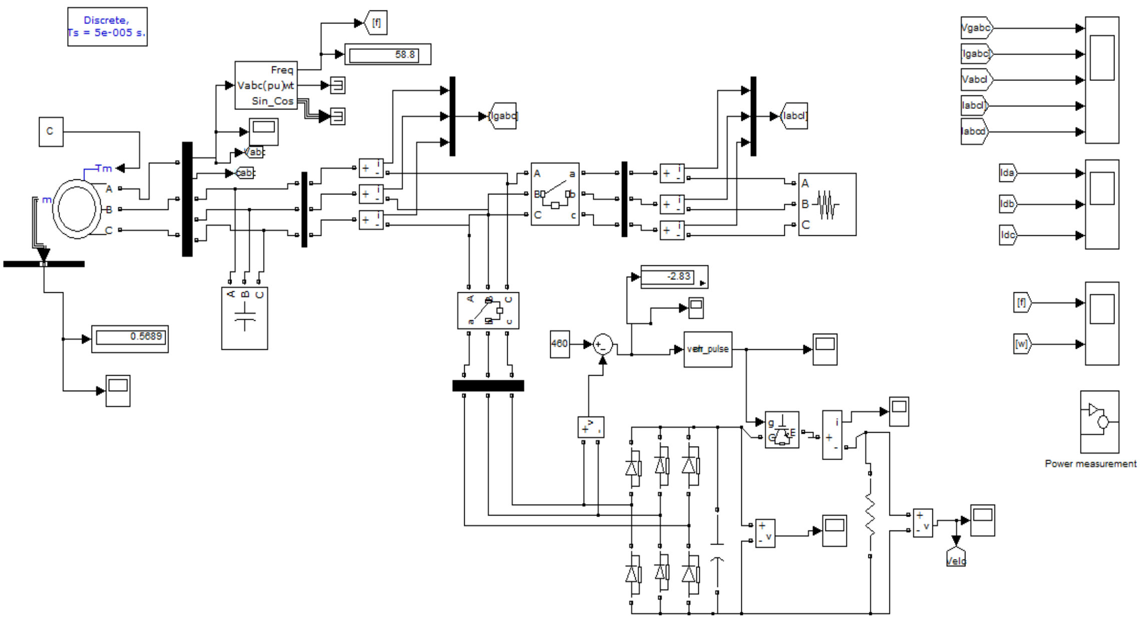

Fig. 1. Simulink model diagram of electronics based DLC

III. DESIGN OF THREE-PHASE ELECTRONICS BASED DLC

For the proper operation of electronics based dump load controller (DLC), proper design and selection of the various components used in electronics based DLC is required. A design procedure is given for the three-phase DLC for a three-phase GIAG of 3730 W, 460 V. The voltage rating of the uncontrolled diode bridge rectifier and IGBT operated chopper switch will be the same and dependent on the r.m.s value of three-phase ac input voltage and average value of the output dc voltage. The output dc voltage is obtained as

$$V_{DC} = \frac{(3\sqrt{2}\ V_{LL})}{\pi} = (1.35)V_{LL}$$

Where V_{LL} is the r.m.s value of the line-to-line voltage of the GIAG. For 3730W GIAG, the line voltage is 460V i.e. $V_{LL} = 460V$

$$V_{DC} = (1.35) * 460 = 621V$$

An overvoltage of 10% of the rated voltage is allowed for the transient condition and hence, the r.m.s value of three-phase ac input voltage will be (506V) with its peak value as $V_{Peak} = \sqrt{2} * 506 = 715.484V$

The current rating of the uncontrolled bridge rectifier and chopper is decided by the active component of input three-phase ac current and is calculated as

$$I_{AC} = \frac{P}{\sqrt{3}V_{LL}}$$

Where P is the power rating of GIAG. The active current of GIAG may be obtained as

$$I_{AC} = \frac{3700}{\sqrt{3}*460} = 4.64404$$

The three-phase uncontrolled bridge rectifier draws approximately quasi-square current with the distortion factor of $\left(\frac{3}{\pi} = 0.955\right)$. the input three-phase ac current of DLC may be obtained as

$$I_{DAC} = \frac{I_{AC}}{0.955} = \frac{4.644044}{0.955} = 4.86287\ A$$

The crest factor of the three-phase ac current drawn by an uncontrolled bridge rectifier with a capacitive filter varies from 1.4 to 2.0; hence, the peak value of three-phase ac input current may be obtained as

$$I_{Peak} = 2I_{DAC} = 2 * 4.86287V = 9.72574\ A$$

So, for the uncontrolled bridge rectifier, the maximum voltage may be 715.484V and peak current may be 9.72574A. The commercial available rating of an uncontrolled bridge rectifier and chopper switch is 900V and 9.72574A. Therefore, rating of the uncontrolled bridge rectifier and chopper switch has been selected as 900V and 9.72574A

The value of the dump load resistance is calculated by

$$R_D = \frac{(V_{DC})^2}{P_{rated}} = \frac{(621)^2}{3730} = 103.38901\ \Omega$$

The value of the dc-link capacitance of the DLC is selected on the basis of the ripple factor. The relation between the value of the dc link capacitance and ripple factor for a three-phase uncontrolled bridge rectifier is

$$C = \left\{\frac{1}{(12fR_D)}\right\}\left\{1 + \frac{1}{(\sqrt{2}RF)}\right\}$$

If 5% ripple factor is allowed in n the average value dc voltage then the capacitance is calculated as

$$C = \left\{\frac{1}{(12*60*103.389)}\right\}\left\{1 + \frac{1}{(\sqrt{2}*0.05)}\right\} = 151.442\mu F$$

Table 1: Three-phase electronics based DLC designed parameters.

Power rating of motor(W)	Voltage rating of the uncontrolled bridge rectifier(V)	Current rating of the uncontrolled bridge rectifier(I)	Voltage rating of the IGBT operated chopper switch (V)	Current rating of the IGBT operated chopper switch(I)	Rating of Dump load resistance (Ω)	Rating of filtering capacitor(μF)
3730	900V	9.72574A	900V	9.72574A	103	151

The designed data thus obtained is used for the simulation studies under balanced and unbalanced three-phase resistive consumer load.

A. Control Scheme of Electronics based DLC

The control circuit of electronics based DLC consists of a voltage sensor for sensing the three-phase ac voltage of GIAG, a comparator for comparing the sensed ac voltage with the reference voltage, a discrete PI controller for processing the error voltage. The output of PI controller is compared with a saw tooth carrier waveform of 1 kHz frequency to generate the PWM switching signal for IGBT operated chopper switch.

IV. SIMULATED RESULTS AND ITS INTERPRETATION

All the simulations have been carried out in MATLAB software package on a 3730 W Squirrel cage Asynchronous motor with Simulation type (Discrete), Sample time (50e-6), Discrete solver mode (Forward Euler), Simulation time (2 seconds) , Relative tolerance (1e-3), Time tolerance (10*128*eps) and ode45 (Stiff/TR-BDF2) solver.

A three-phase electronics based dump load controller for a three-phase GIAG is designed. From the design data, voltage and current rating of the uncontrolled rectifier bridge and chopper is selected to be 900 V and 9.7 A. The dump load resistance and DC link capacitor are selected to 103 Ω and 151 μF for the simulation study under balanced three –phase resistive consumer load.

A three-phase star-connected Asynchronous machine of 3.73 kW, 460 V, 60 Hz, 4 poles is used as GIAG. The GIAG is driven by a three-phase alternator. To generate rated voltage i.e. 460 V at full load, three-phase capacitor of appropriate value is connected across the machine stator terminals.

Fig. 2. shows the transient waveforms of voltage generated by three-phase GIAG voltages (V_{gabc}), three-phase generator currents (I_{gabc}), three-phase resistive load currents (I_{abcl}), three-phase DLC currents (I_{ad}, I_{bd}, I_{cd}), generated power (P_{gen}), consumer load power (P_{cload}) and electronic load power (P_{eload}) .

It is observed from the simulated results [Fig. 2] that when the three-phase balanced resistive load of 2 kW is switched ON at 0.7 sec, consumers load current increases and the DLC currents decreases. It depicts that transfer of power takes place from three-phase DLC to the balanced three-phase consumer load and GIAG experiences constant load on it and hence maintain constant voltage and frequency [Fig. 2 and Fig. 3]. It is also observed that at this time power fetched by the dump load (P_{eload}) is nearly zero. With the switching OFF of one phase at 0.8 sec and another phase of load at 0.85 sec, the load becomes unbalanced. Under these operating conditions, consumer load current decreases and the DLC currents increases. It depicts that transfer of power takes place from balanced three-phase consumer load to the three-phase DLC and GIAG experiences constant load on it and hence maintain constant voltage and frequency. At 0.9 sec one-phase and at 0.95 sec another phase of load is reconnected on GIAG. At the instant of switching OFF the three-phase balanced resistive consumer load at 1.2 sec, load current becomes zero and DLC current increase which gives an indication of transfer of power from consumer load to DLC such that GIAG experiences a constant load on it and maintain constant voltage and frequency [Fig. 2 and Fig. 4]. It is observed from Fig. 4 that electronic load power decreases whereas the consumer load power increases with increase in balanced /unbalanced consumer load so that the load on the GIAG remains constant.

Table 2: Simulated Balanced and unbalanced operating conditions.

No of Phases connected	Time of connection /disconnection /reconnection	No of phases disconnected	No of phase reconnected	Nature of three-phase load
a, b, c(3)	at 0.7 sec	Nil	Nil	Balanced
b, c (2)	at 0.8 sec	a (1)	Nil	Unbalanced
c (1)	at 0.85 sec	a, b (2)	Nil	Unbalanced
b, c (2)	at 0.9 sec	Nil	b (1)	Unbalanced
a, b, c(3)	at 0.95 sec	Nil	a, b (2)	Balanced
Nil	at 1.2 sec	a, b, c (3)	Nil	No load

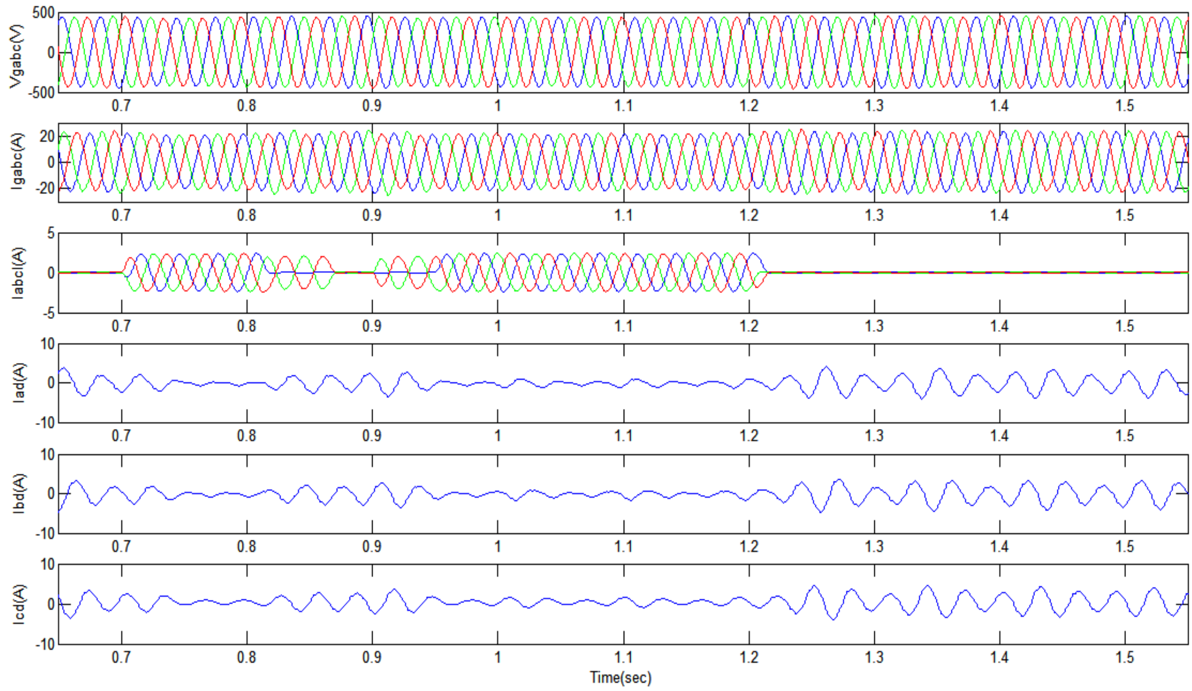

Fig. 2. Simulated transient waveforms of voltage generated by three-phase GIAG (V_{gabc}), three-phase GIAG currents (I_{gabc}), three-phase resistive load currents (I_{abcl}), per-phase DLC currents (I_{ad}, I_{bd}, I_{cd}).

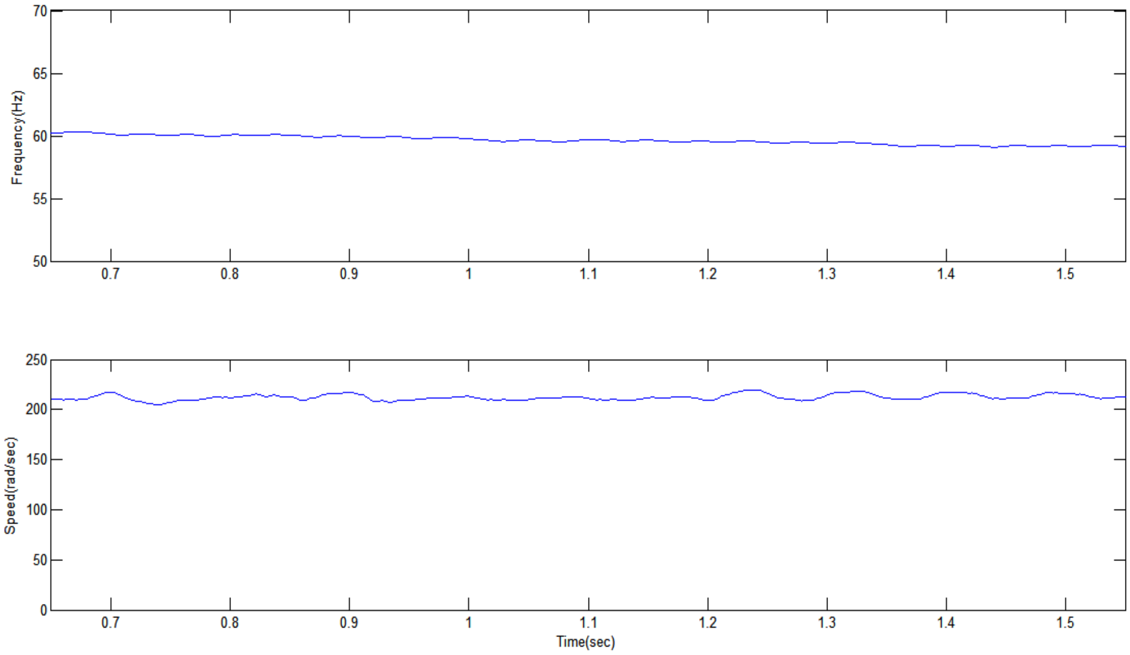

Fig. 3. GIAG frequency and GIAG speed.

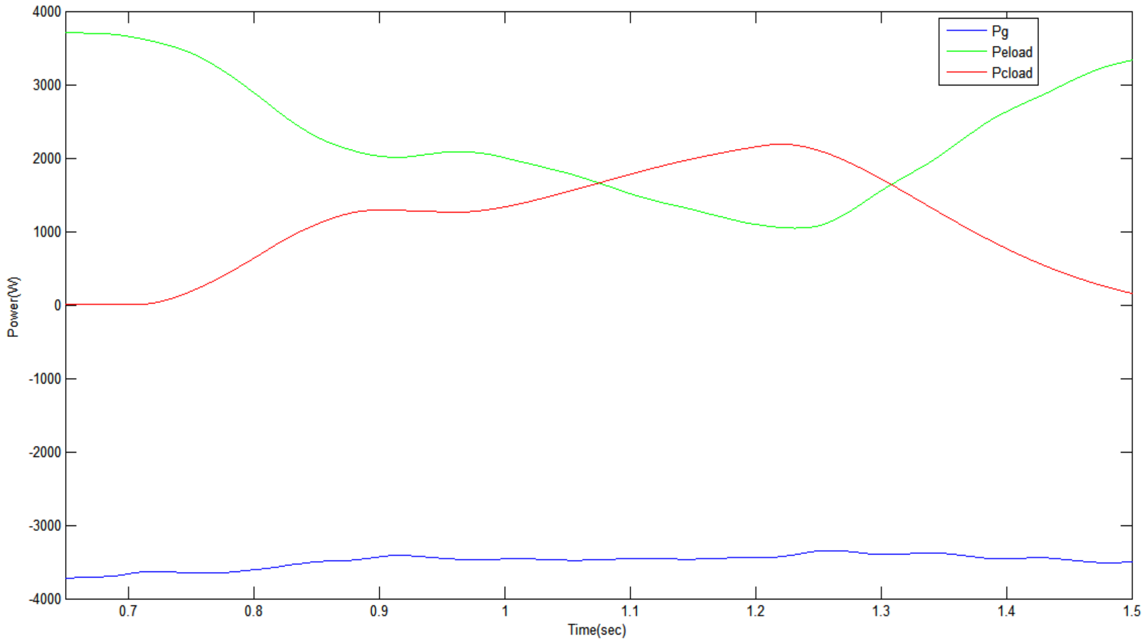

Fig. 4. Variation of power generated by GIAG (P_{gen}), consumer power (P_{cload}) and electronic load power (P_{eload}).

CONCLUSIONS

From the simulated results, it has been concluded that the developed DLC for GIAG maintains both voltage and frequency constant despite the variation in balanced and unbalanced consumer resistive load. An electronics based dump load controller has been designed and developed in MATLAB/SIMULINK for the three-phase GIAG. Using the designed criteria described in this paper, volt and ampere rating of the uncontrolled bridge rectifier and IGBT operated chopper switch, value of dump load resistance and value of dc filtering capacitance for the three-phase DLC for the three-phase GIAG can be estimated for electrical power generation in pico-hydro applications.

APPENDIX-I

MACHINE DATA

Parameters	Ratings/Specification
Rated Power	3730 W
Rated Line to Line Voltage	460V
Rated Frequency	60Hz
Pole Pairs, P	2
Stator Resistance, R_s	0.01965 p.u
Stator Inductance, L_{ls}	0.0397 p.u
Rotor Resistance, $R_{r'}$ (referred to stator side)	0.01909 p.u
Rotor Inductance, $L_{lr'}$(referred to stator side)	0.0397 p.u
Moment of inertia, J	0.089 Kg-m^2
Mutual Inductance, L_m	1.354

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