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# Simulation and Performance Analysis of Discrete Load Controller for Micro-Hydropower Plant

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*Abstract:* **Electronic load controller (ELC) has been an in-dispensary part of governor free Micro hydro plant for frequency control for a long period of time. Conventional ELC consists of thyristor-controlled dump load system; in which firing angle regulates the amount of power to be fed into dump load. Such ELC units suffer many drawbacks, including injection to current harmonics, drawing high reactive current from the source. This study tries to address these issues by introducing a Discrete Load Controller (DLC). DLC controls the load by controlling the number of resistors to keep it ON or OFF without chopping source voltage. The system layout and control scheme are developed in Matlab® Simulink environment and different disturbance are introduced for dynamic response. The result shows that the DLC functions well, by generating less harmonics and consumption of reactive power; which otherwise are to be supplied by the generator itself. Further the DLC is also capable of regulating frequency at designated value in spite of all loading condition. Also, the result obtained from simulation is validated experimentally.**

***Keywords*** **—** Micro Hydropower Plant, Discrete Load Controller, Synchronous Generator, Total Harmonic Distortion, Load.

## I. Introduction

Rising environmental concern, increasing fossil-fuel depleting rate are favoring for the proliferation of renewable type distributed generation (DG) units around the world. In rural and remote areas, the DG has drawn further attention for the standalone operation due to the high cost and complexity of transmission network. Subject to availability, micro hydropower plant (MHPP) system is very attractive among the renewable sources, owing to its mature technology, minimum civil work, and cheap installation cost. In many developing countries, the MHP systems are located in hilly areas and operated in stand-alone mode. This demands the robust and reliable technology manageable by the local people is required, which applies for the choice for the controller, generator, and turbine technologies [1].

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By virtue of its small size and geographical constraints, MHPPs are not equipped with storage and demand in instantaneous basis. Due to small in size, MHPPs are not equipped with the governor control. Since power generation is left uncontrolled, the balance in power is maintained by using a controlled ballast load. In particular, the ballast load is controlled by using electronic load controller (ELC), which provides a buffer medium between the fluctuations in load. Similar function can be done by Discrete Load Controller. DLC maintains a constant electrical load on the generator in spite of changing user loads. It maintains a constant generator output by supplying a secondary ballast load with the power not required by the main load. Consider Plant is running at near full load and governed by an DLC. During the lightly loaded condition, speed of the turbine increased, the DLC sense it and it diverts the surplus power to ballast load. Thus, in spite of change in consumer loads the total load on the generator remains constant. And at the time of full load, the ballast load is cut off and total power is supplied to the consumer load or main load. Ballast load is usually a heavy-duty resistive load such as a water heater, which acts as a sponge to soak up any extra power, preventing it from overloading the village system [2].

There are basically two types of generator employed with MHPs: squirrel cage induction generator (SCIG) and salient pole synchronous generator (SG). SCIGs are often used with small generator, in which terminal voltage is taken as control variable to determine the surplus power; while SGs are used with larger ratings and the frequency is considered as the controlled variable. The frequency of system is sensed and then subjected to the controller (PI controller) to produce actuating signal. The actuator signal is either the firing angle (for thyristor-based actuator, working as AC voltage control), or the duty cycle (IGBT based actuator, working as rectifier) [2-3]. While the ELC systems provide good speed control of generator rotor, they have issues as they draw reactive and non-linear/harmonic current.

To overcome these drawbacks, DLC system is proposed by which the reactive power and harmonic current in load is reduced as per the prevailing standard. Consequently, the generator supplies the sinusoidal current through its terminals.

## II. **Overview of system**

The layout consists of three subsystems; generating unit, DLC unit and load unit and is illustrated in Figure 1. The generating unit includes a synchronous generator with excitation control for voltage regulation. The prime mover includes cross-flow Pelton turbine with governor-free operation, so the turbine is exposed to free flow of water. Thus, the generator is running at its rated value (5 kW) throughout the time. Discrete load consists of number of resistive loads each of same rating which is turned ON or OFF by the help of circuit breaker and the circuit breaker is activated by the help of controlled signal generated from the PI controller.

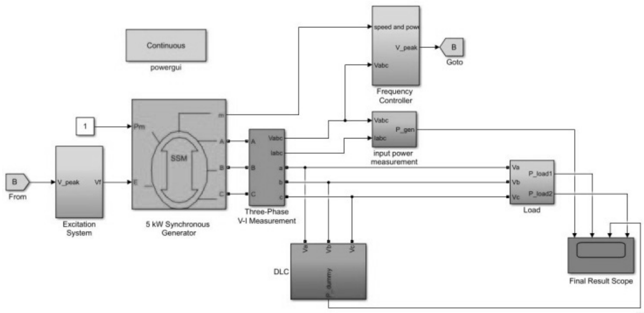


*Fig. 1. Whole simulation model of 5 kW micro hydropower plant with DLC*

### *A. Generator Unit*

This is the main unit to generate electricity. Here, the rotor of synchronous generator is rotated by the help of turbine. Synchronous Generator used in a simulation has a rating of 5 kW operated at 400 V line to line voltage and frequency of 50 Hz.

### *B. Load Unit*

Here, 1 kW load and 2 kW load are used for the simulation purpose. Initially, 1 kW load is connected to the 5 kW synchronous generator then after 4 second, 2 kW load is added across the 1 kW load such that total load connected to the generator is 3 kW.

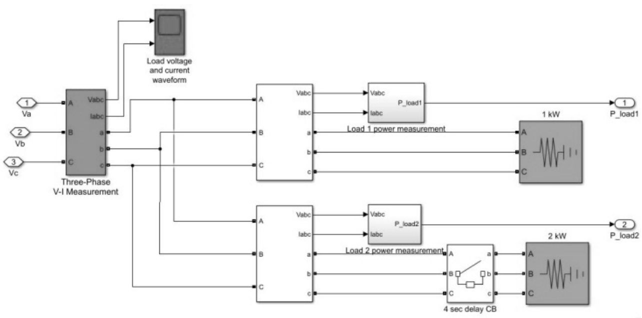


*Fig. 2. Block diagram of load*

### *C. DLC unit*

This unit is similar to ELC but contains a set of resistors which are used as dummy load. The main function of this unit is to consume the excess power that has not been consumed by the load. So that the total load across the synchronous generator remains constant. It consists of 10 numbers of dummy load each of 0.5 kW. So that if the power consumed by the consumer is zero, total power is consumed by the DLC dump load. Detail block diagram of DLC is shown in Figure 3.

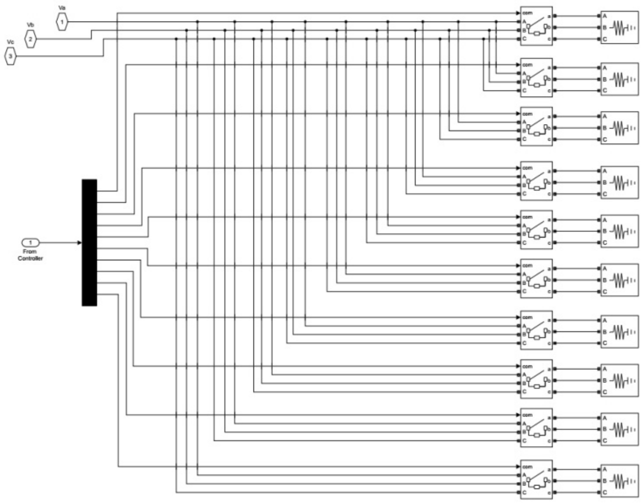

*Fig. 3. Detail of DLC block diagram*

## III. **Proposed control system scheme**

The control system scheme is responsible to generate the controlled signal which is used to turn ON or OFF the set of resistor bank of the DLC block. Here, the rotor frequency of synchronous generator is sensed and is then compared with the reference frequency. For the easiness, rotor frequency is sensed in per unit (p.u.) and reference frequency is 1. Error thus obtained is passed to PI controller which is then processed to generate the controlled signal to turn ON or OFF the set of resistor bank of the DLC block. Frequency controller block is shown in Figure 4.

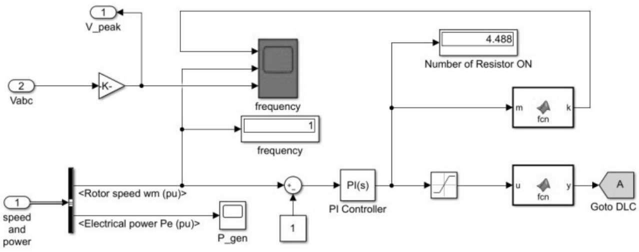


*Fig. 4. PI controller simulation block diagram*

## IV. **Results and Discussions**

The layout and the component model presented in above sections are developed in Matlab/Simulink® platform. By introducing loading as disturbance input, the control scheme is tested through the responses of different controlled variables, such as Source current, DLC current, load current, system frequency, THD of source current, THD of load current and THD of DLC branch current. Here, Simulation is run for 8 sec, and after 4 sec there is increment in load. The following sections elaborate the findings of the simulation results.

The response of frequency is shown in Figure 5. Here, the frequency of system is stable even when the load changes from 1 kW to 3 kW after 4 seconds.

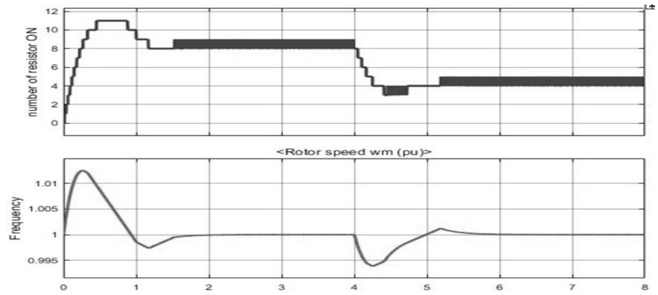


*Fig. 5 Number of Dump resistor ON and Waveform of Frequency of voltage generated by synchronous generator*

The waveform of generated voltage and current generated by the synchronous generator is sinusoidal in nature as shown in Figure 6, but while using ELC, the waveform of source voltage and current generated by synchronous generator was not sinusoidal.

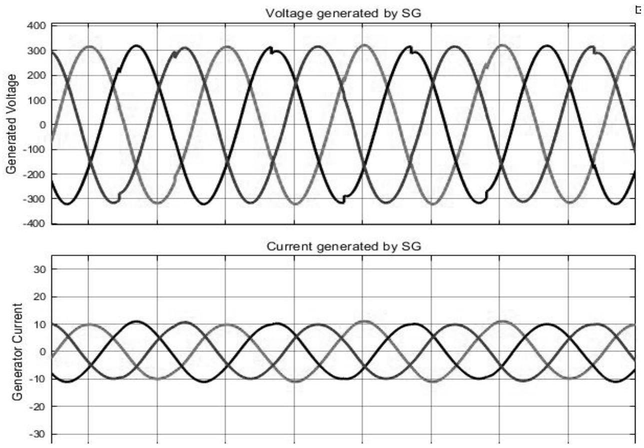


*Fig. 6. Waveform of voltage and current generated by SG*

Waveform of voltage across ballast load and current through ballast load when load is 1 kW and 3 kW is shown

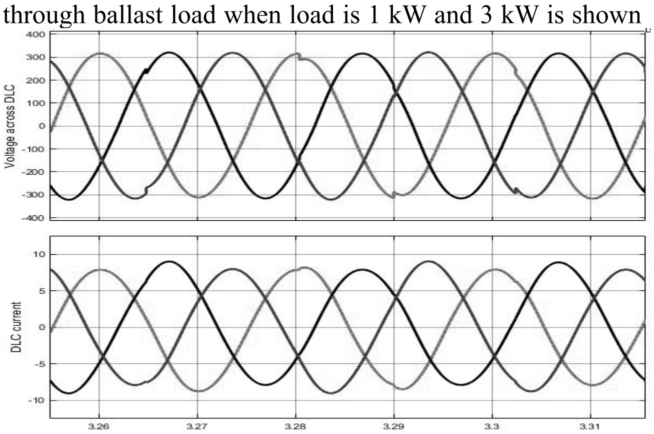


*Fig. 7. Voltage and current waveform of DLC when load is 1 kW*

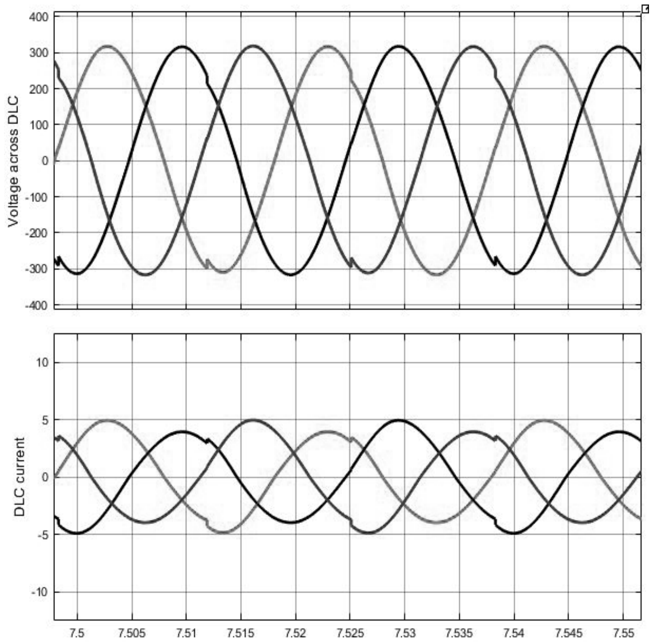


*Fig. 8. Voltage and current waveform of DLC when load is 3 kW*

in Figure 7 and 8. Also the waveform of voltage and current through load when the load increases from 1 kW to 3 kW is is shown in Figure 9.

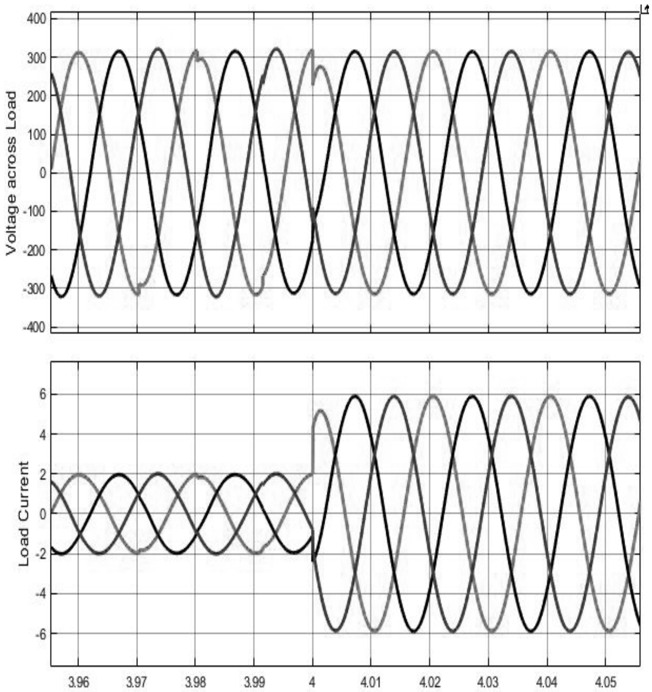


*Fig. 9. Voltage and current waveform of load*

To analyze the THD of the source current, ballast current and load current, Fast Fourier Transform (FFT) is used to measure the order of harmonics with the fundamental frequency. The Total Harmonic Distortion of the current is shown in Table 1 and Table 2 respectively for both type controllers.

TABLE 1

SUMMARY OF SIMULATION RESULTS OF THD OF 5 KW PLANT HAVING ELC

| Simulation time | 0 to 4 sec | 4 to 8 sec |
|---|---|---|
| THD of Source Current (%) | 9.38 | 7.34 |
| THD of Current through ELC (%) | 13.47 | 32.73 |
| THD of Load Current (%) | 32.91 | 33.91 |

TABLE 2

SUMMARY OF SIMULATION RESULTS OF THD OF 5 KW PLANT HAVING DLC

| Simulation time | 0 to 4 sec | 4 to 8 sec |
|---|---|---|
| THD of Source Current (%) | 6.95 | 5.36 |
| THD of Current through DLC (%) | 3.09 | 5.51 |
| THD of Load Current (%) | 2.16 | 2.45 |

It is found that the supply current is distorted due to the dominancy of fifth, seventh and eleventh order of harmonic spectral components and the measurement of THD is 9.38% and 7.34% when ELC is used for 1 kW load. For the same load when DLC is used THD is 6.95% and 5.36% respectively which is nearly equal to range of standard harmonic limit (5%). THD of DLC current and load current is also at the range of standard harmonic limit for plant having DLC.

Simulation result is also experimentally verified, for that purpose same 5 kW ELC system and 5 kW DLC system is compared and the result obtained is shown in Figure 10 and 11.

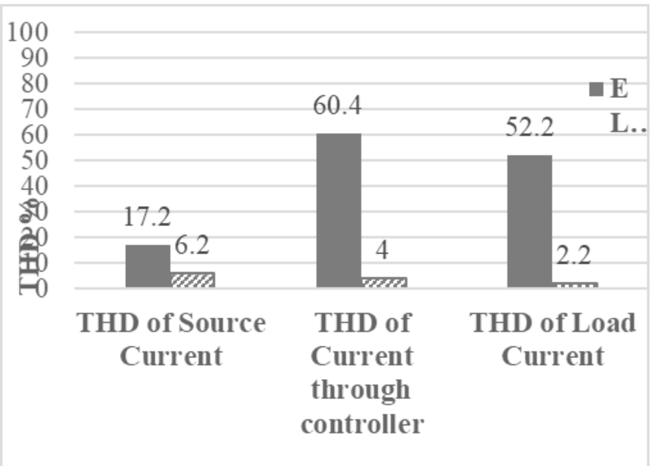


*Fig. 10. Comparison of THD % of ELC and DLC when load is 1 kW*

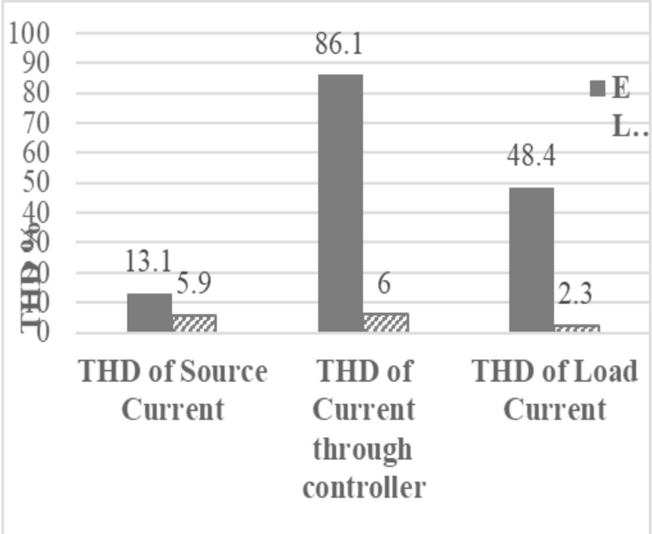


*Fig. 11. Comparison of THD % of ELC and DLC when load is 3 kW*

Experimental results show that use of DLC in MHPP, reduces THD to the range of standard harmonic limit.

## V. Conclusion

This study presents Discrete Load Controller system, which balance the power generated by synchronous generator by controlling the number of resistors to keep it ON or OFF without chopping source voltage. It is capable to work as conventional electronic governing unit and helps to reduce harmonics and reactive power of the system.

When the result is compared in terms of total harmonic distortion of 5 kW plant having both type of controllers, THD of source current, when load is 1 kW, using ELC and DLC reduces from 17.2% to 6.2% respectively while THD of current through ELC and DLC decreases from 60.4% to 4% and THD of load current falls from 52.2% to 2.2% while using ELC and DLC respectively.

Furthermore, after increment of load to 3 kW, THD of source current using ELC and DLC reduces from 13.1% to 5.9% respectively while THD of current through ELC and DLC decreases from 86.1% to 6% and that for THD of load current falls from 48.4% to 2.3% while using ELC and DLC respectively.

Experimented result and analysis manifests that, employing DLC in micro hydropower plant, THD of the system reduces to range of standard harmonic limit (5%).

## VI. Recommendation

Different micro hydropower plants having same controller (ELC) have been interconnected to form a mini grid system. But interconnecting of different micro hydropower having different controller can be further extension of this thesis. Control strategies to interconnect different micro hydropower so as to form mini – grid system can be done with the help of this thesis.

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