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Discrete Electronic Load Controller for minimizing Total Harmonic Distortion in Micro Hydro Power Plants

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Abstract

Micro hydropower systems have emerged as crucial contributors to sustainable energy in remote areas, bringing forth the need for meticulous integration into power grids. Total Harmonic Distortion (THD) stands as a pivotal metric, with elevated levels leading to inefficiencies, equipment degradation, and operational challenges. This abstract presents an innovative approach to tackle this issue by employing a Discrete Electronic Load Controller (DELC) within the realm of multiple Micro hydro power Plants (MHPP). In pursuit of optimizing power quality and operational efficiency, the primary objective of this research is to develop and implement an advanced control strategy utilizing DELC to minimize THD in systems with multiple MHPPs. The comprehensive methodology encompasses an exhaustive literature review, system characterization, DELC design, simulation and modeling in MATLAB, and optional hardware implementation, thus, the obtained performance evaluation involves a thorough comparison between the Discrete Electronics Load Controller and conventional control strategies and the simulation results showcase the remarkable reduction in THD achieved by the DELC, validating its efficacy over traditional control methods. An iterative process optimizes Proportional-Integral-Derivative (PID) parameters, ensuring minimal THD while maintaining system stability. Robustness testing involves scenarios with various faults and load variations, affirming the robustness of the proposed DELC strategy. This research contributes significantly to sustainable energy endeavors by demonstrating the effectiveness of DELC for THD minimization in multiple MHPP. Beyond enhancing power quality, the optimized control strategy fortifies system stability, positioning micro hydropower as a reliable energy source for seamless integration into broader power grids. Looking ahead, future investigations could delve into the scalability and adaptability of the proposed DELC strategy for diverse micro hydropower configurations and network conditions. Additionally, assessing the economic feasibility and long-term performance of DELC-controlled MHPP systems will be instrumental for comprehensive insights into sustainable energy solutions. This research provides valuable guidance for the ongoing evolution of micro hydropower systems in the quest for sustainable and efficient energy sources.

1. Introduction

1.1. Background

The world faces the issue of efficiently utilizing renewable energy sources to meet the growing demand for electricity as well as to protect and restore the environment. That's why it is essential to keep atmosphere fresh and clean by minimizing the CO_2 release into our surrounding environment. Among the various methods, micro hydro power plants are the best examples in the context of Nepal and similar hydro prone areas.[1]

Conventional large hydropower plants have problems like long gestation periods, ecological changes, loss due to long transmission lines, submergence of valuable forests, and very large budgets. They also require the rehabilitation of large populations from the area to be submerged. Due to all these factors large hydropower plants are unfavorable in the scenario of underdeveloped countries like Nepal. On the other hand, Micro

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Hydropower Projects (MHP) is free from these aspects.

For operating micro hydro power it is depends upon river flow that is Run of River (ROR) type. So, the output of generator depends on rated condition of current, voltage and speed, but the load on consumer may vary, when the load of consumer increases, the turbines begins to decelerate and decrease in frequency and vice versa. And traditional designs of ELCs were constant frequency modes because they were operated in an isolated means. But in this scenario, due to the increased number of micro-hydro power plants in the rural nearby areas of Nepal, the possibility of parallel operation of two micro-hydro power plants has been raised. So, the point of reliability and energy security the parallel operation of them would possible and beneficial.

1.2. Possibilities of parallel operation

Now the variation in the consumer load connected is balanced by the use of load controllers such as electric load controllers (ELC) and discrete electronic load controllers (DELC), which divert the extra power to a dump load. ELC regulates the frequency of the generator through monitoring of consumer load variation and automatically transfers any surplus power produced by the generator in an additional load known as a dump load, so that, the total output power of the generator remains equal to its consumed power.

Now, in this research two micro hydropower sources to a single grid and model the simultaneous operation of ELC and DELC in this simulation-based thesis (if one MHP uses ELC and the other uses DELC). After succeeding in such a scheme and then a common hybrid controller will control the whole interconnected micro grid load by a sharing strategy.

1.2.1. Controlling of firing angle (α):

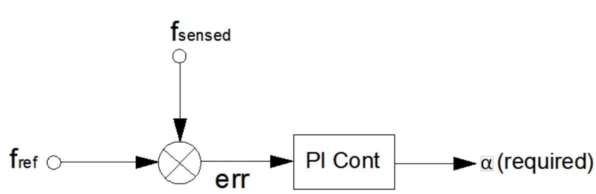

Figure 1: Firing angle controller block

Here, the reference frequency is compared with the sensed frequency in a system. Then, the error signal is fed to the PI controller which generates a firing angle (α), which is the required firing angle for the system.

ELC does have some disadvantages which are given below:

- It chops the waveform of voltage across the dump load.
- Here, the dump load current is non-sinusoidal and it lags the generated voltage.
- There is also a harmonics problem on ELC.
- Here, the dump load also consumes reactive power due to a lagging current.

To overcome these disadvantages of ELC, a Discrete Electronic Load Controller (DELC) will be developed in this research.

1.2.2. Discrete Electronic Load Controller (DELC)

In the Discrete load controller, the harmonics that are drawn during the operation of thyristor-based ELC by the load are prevented, as a set of resistors is used as the dummy load. A certain value of resistance is chosen as per the generation capacity of the generator and the numbers of resistors are chosen according to the precision required. Since it is a discrete controller, the fluctuation in a certain small range of power is neglected so that the frequency that changes in turn won't affect the system considerably.

1.3. Problem statement

In a micro-hydro system, the variation in consumer load can cause a mismatch between power generated and power consumed, leading to problems in the system. If the consumer load decreases, the rotor accelerates, and the frequency sensor detects a rise in frequency. For the generation of an error signal it is comparing the reference frequency with the detected frequency, which is then passed through the controller to generate an appropriate firing angle for the thyristor. This causes the extra power to be dumped in the ballast load or dummy resistance. The reverse process occurs in the case of an increase in consumer load.

1.4. Objective

The research main objective is stated as,

- To develop a control strategy for operating two nearby micro hydropower plants.

The specific-objectives of the research are summarized as:

- To simulate DELC method and compare with ELC.
- To divert excess energy to ballast loads.
- To enhances power distribution efficiency.

1.5. Scope and limitations

Experimental work can be performed under the parallel operation of micro hydropower plants and controlled by a common controller simply known as a Master controller which will be kept close to the bigger plant among them that of parallelly connected. After implementing such a proposed scheme, a DELC controller with PWM control techniques harmonic arise in the overall system will minimize and improve efficient operation can take place instead of Conventional ELC as a system controller.

In this kind of project, frequency control and synchronization are difficult and time consuming processes. The system's permissible tolerance for frequency restricts the operation of such systems and changes in loading conditions. Therefore, there is a need for the finest strategies that can minimize these operable limits and deliver the best outcomes with efficient operation to take care of the overall system and to acquire healthy operation within the bounds of the system.

2. Literature Review

In this research, the use of micro-hydro power plants (MHPs) has become increasingly popular in recent years due to their ability to provide a sustainable and continuous source of renewable energy to hilly and rural areas. However, MHPs have several limitations that need to be addressed to maximize their potential. One of the main limitations of MHPs is that the variable discharge of water flow to the turbine, which results in variations in output of generator power and frequency. Another limitation is the lack of technical knowledge in resource prone areas, which can support the development of hydropower. In addition to, the discharge and water available for expanding power output when demand increases is depends on seasonal flow for water availability. Which is explained in various papers and some are listed here.

2.1. Review of different papers

The paper discuss about the power generation, consumption, and control and governor as a controller, its limitation in micro hydro power plants, and the possibility of an electronic load controller and its benefits and power balance by ballast load. The load sharing strategy and then harmonics arise by chopping process and then need to the proper method for handling such harmonics in power source by using ELC.[1]

This paper also offers some useful and potential solutions to address the control, synchronization, protection, and coordination problems that perceive when MHPPs are connected to a grid. [2]

This paper has identified several shortcomings of an isolated micro hydropower system, including limited generation capacity to meet the demand, supply cut-off during breakdown or planned maintenance of the power plant, limitation of power to the motor due to Inrush current, lower load factor due to limited consumer, same consumption pattern, difficult to improve quality of power, and impossible to provide regular water for milling and irrigation. As a solution, Bajagain et al suggests building a micro grid to help overcome many of the drawbacks and difficulties of distributed systems. [3]

Resent era in the electricity and merchandising and regulation, Maximum power tracking (MPPT) technology represents a perfect solution in overall context of economics and environment. In isolated area micro grid is the continuous and most reliable primary source of energy for present as well as for future so variable speed is the efficient way to optimize the micro grid system. [4]

They studied the Dynamic electronics load controller for self-excited induction generator for three phase control as voltage and frequency control under varying load condition. [5]

In distributed generations, an improved load sharing strategy has been employed for a micro grid conventional voltage dips and frequency control results that the load sharing and active power as unacceptable range. This paper seeks the algorithm for load sharing in the island micro grid. For the verification of this strategy it considers as feeder losses, DG ratings, line impedance drops and the effect of the local load of DGs. This paper developed for variable loading condition as an improved power-sharing strategy that also facilitates PCC voltage regulation. The suggestions got from this paper were the capacities of DGs of about 100kW, and then the micro grid runs often at low voltage distribution levels. [4]

In this research work, it seeks as in their research paper that the micro-hydro power (MHP) system is regarded as a non-dispatch able generating unit; an effective storage medium is required for storing the surplus energy which can subsequently be reused during peak load and time when there is insufficient flow of water. To utilize the power generated from the MHP system optimally there is a wide-scale research practice of employing technologies with wind/PV systems, which can also apply to MHP. [6]

In this paper, the home energy management system with renewable energy has been researched recently that micro hydropower (MHP) built on a run-of-river may be very beneficial for rural electrification. While doing so, for the off-grid operation mode of the hybrid energy system, with plenty of research on wind power-pumped hydro storage (WP-PHS) hybrid systems for rural electrification or home management, the results show that it can effectively improve energy utilization efficiency and the reliability of power supply systems.[7]

The research carried on at (2022), research power management in solar PV-micro hydro hybrid systems using power angle control strategy with a new term 'syncronverter'. The most effective control challenges in the hybrid system are frequency stability, especially when they are in the face of load-generation imbalance and multiple uncertainties. Research about multiple micro hydro sector said that the standalone micro grid is modeled in the MATLAB/Simulink environment. For the power control, the power angle control method (PAC). [8]

This research focuses on the conventional ELC and gave the remedies for such limitations of C-ELC. Power may be wasted in a dump load at the generator site, in a conventional ELC system. The solution made by installing separate ELC for individual power plant. Whereas, the excess power of each household can be utilized for domestic water heating, supporting to health-related benefits. [9]

This research explained about MHPP and load controllers for the quite interest for researchers as well as developers for paramount importance to keep the speed (frequency) as constant level.

The factors that change the simulation results are noticed that the stator current, mechanical power output, excitation voltage, the output of the generator, power across consumer load, and dump load as a result of the change in demand load. [10]

This research discussed a controller requirement to sustain the quality of the generated power in the powerhouse that is the RMS voltage and power frequency must remain within tolerable limits while neglecting excess voltage harmonics this controller in the powerhouse can be constructed based on the two listed methods as the some reactive power should be provided by the controller to keep the RMS voltage close to constant across the load. The reactive power must be variable that concerning system PF, total consumer load, and the prime mover speed. The series compensation scheme or by long and short shunt compensation schemes is used to provide the overall essential reactive power in the system.

In the second method, ELC is used as a controller. The ELC can be formed in numerous ways as DC chopper, binary weighted switch resistor, uncontrolled rectifier, and thyristor-based low-frequency AC chopper. Although the ELC method of control are very simple, reliable, and cost effective however they suffer from a major drawback, the waste of a large amount of the energy that generated and is supplied to the ballast load.

To minimize above listed problem like harmonics induction, power loss, voltage dips and so on the Distributed ELC (D-ELC) had been proposed in this paper. In this proposed approach simplified single-phase controller are distributed among all the residential in the affected group. The DELC figures out or calculate the tentative power used in the household, and if that power is less than a specified pre-defined value, the difference in such power is transferred to a low or medium-power rated appliances i.e. domestic water heater, rice cooker, and space heater.[9]

The paper had been studied that the synthetic inertia frequency support as a control method for standalone and grid-connected MHPP. A power converter between the grid and machine to control the consumption of power during pumping mode is used as modern pump storage MHPPs. The power electronic converter drops the capability of the rotating mass of the machine to provide to the grid inertia by making it independent of the grid frequency. By controlling the power converters, the problem is solved through the in such a way that the inertia effect is incorporate and termed synthetic inertia. The paper tries to explain the control provisions applied in theoretical way for the frequency, voltage, and inertia control for both the ON-grid and isolated/OFF-grid modes.[11]

The research is carried on the studied about better design and operation of isolated micro grids. This study focuses on the supply side with prominence on make certain the reliability, moderateness, and security of the supply of the electricity to meet consumer demand. This paper identifies the problem by surveying numerous residents across various micro grid sites in Nepal and found that micro grid designers and operators keen on to minimize costs and improve reliability when serving rural communities. After research, it can be said that the demand-side management occasions can exchange cost and reliability and place loads according to consumer inclinations.

For grid extensions, many rural areas have special characteristics including an insufficient infrastructure, geographical hindrance, skimpy populated arrangements, and limited economic provisions with subsequent low electricity demand resulting in fewer returns on investment for usage. In these cases, grid extension may not be the best or most viable option. [12]

This paper discussed about parallel operation of synchronous generator and induction generator and its control strategy.Hence by selecting proper control strategy both generators work and able to develop proper load sharing.[12]

2.2. Research gap

After reviewing various literatures there is a research gap in renewable energy sector. In micro hydropower, the type of controller such as Discrete- Electronic load and its usage for the master controller has not been studied at. Furthermore, a comparison of the Electronic Load Controller and Discrete Load Controller has not been studied. These research gaps provide an opportunity for further investigation and exploration. Additionally, a detailed analysis of Total Harmonic Distortion (THD) of source current, controller current, and load current is also an opportunity for researchers.

3. Materials and method

3.1. Model of overall work

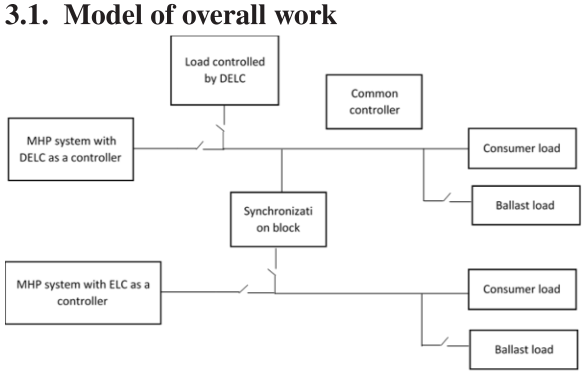

Figure 2: Basic block diagram of MHPP with controller

In order to simulate a system for parallel operation of ELC and DELC, it is essential to have clear understanding and knowledge about their working and operation. For the simulation, following schematic diagram of multiple hydro powers which are operated as isolated mode of following specification is shown below:

1. Synchronous generator-1(G1): 60kW, 400V, 50 hz, 1500 RPM Operated by hydro turbine and serves as local load and controlled by ELC called as ELC-1. At first, this mode of operation is done for isolated operating mode. And the further step this solely operated MHPP will be connected for parallel mode as a small grid simply a micro grid.
2. Synchronous generator-1(G2): 40kW, 400V, 50 Hz, 1500 RPM Operated by the hydro turbine and serves as local load and is controlled by ELC called -2. At DELC first, this mode of operation is done for isolated operating mode. And further step this solely operated MHPP will be connected for parallel mode as a small grid simply micro grid.

The multiple-generation system is then connected in parallel connection and supplied by individual local load, while one generation is shut down due to various reasons and the other generation supplies the overall system load.

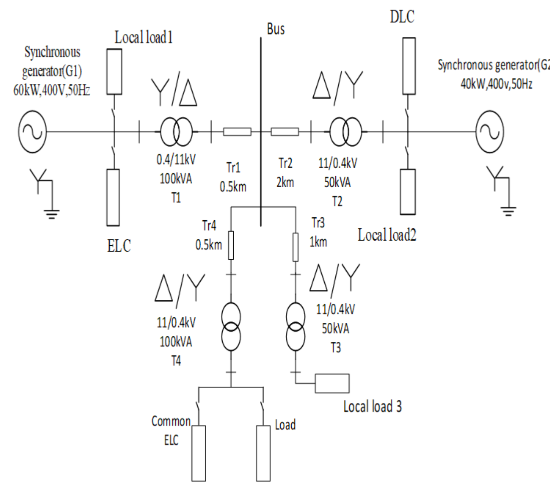

Figure 3: SLD showing the parallel operation of two nearly located MHPP

Figure 3 of two generators of different capacities, each generator supplies its load, and their respective controller acts as a governor function for making power constant. Two separate controllers are used for serving their load and after synchronization; the master controller can serve as a controller to control the overall system. Such types of controllers are hybrid and can work for chopping for partial load perturbation where in a large load change scenario to reduce such impact on load and system stability, it is needed to operate separately and operate different controllers and then the system is operated in isolated mode.

3.2. Common Discrete Load Controller

An improved controller proposed in this research will be a modified discrete electronic load controller, which works as a control switch by taking numbers of resistive load like discrete behavior. Main purpose of this study is to obtain stable operation while connecting in two operating MHPPs and reduction of THD arising in firing angle control action like chopping signal, which was previously operated at isolated mode. A common controller is placed near the larger power generating plant among parallel connected plants which controls separate controllers by necessary action. For setting stable voltage and frequency operation and obtaining proper load sharing as a load-changing pattern, ballast load switching by activating the necessary firing angle generated by the signal generator which is initiated by

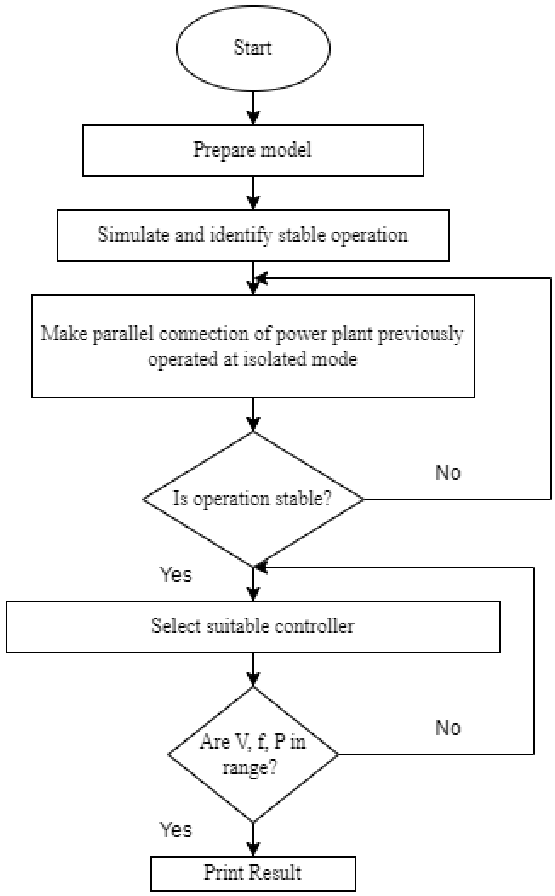

Figure 4: Flowchart of the overall system

the PI controller. To operate these schemes efficiently, the THD of the chopping signal wave needs to be minimized. The proposed scheme will try to minimize such harmonics present in the source by modeling discrete ELC and discrete controller works as step-switching mechanisms.

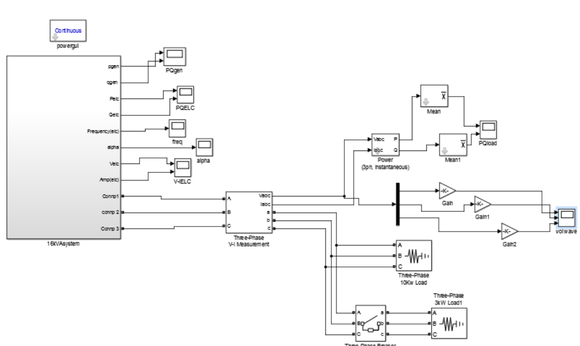

Figure 5: Simulation of ELC

3.3. Simulation of ELC

Here, a simulation model of a 16 kVA Synchronous generator (SG) with ELC as a load controller is shown in Figure 5 above. First of all, there is a 10kW of initial load and then a load of 3 kW is added after 8 seconds. A total of 13kW of resistive load is connected to this generator and other extra amount of power is consumed by ELC. A subsystem is created for the 16 kVA ELC-controlled MHPP system. In the subsystem, various blocks and parameters are modeled and settled for appropriate operation on the simulation model and then it can be further implemented in real-time system. So, to make the simulated model compatible in real time system some standards available in our system should not be changed or altered. Like Standard frequency, standard voltage, switching or breaker operation time, and so on maintained within system limits.

3.4. Simulation of 31.3 kVA MHP with DLC

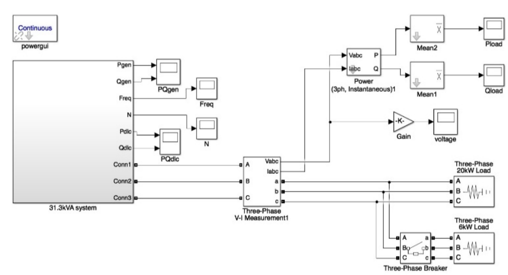

Figure 6: DELC system

Here, a simulation model of 32 kVA Synchronous generator (SG) with DLC as load controller is as shown in the figure above. First of all, there is a 20kW of initial load for 8 seconds and then load of 6 kW is added after 8 seconds. A total of 26kW of resistive load is connected to this generator and other extra amount of power is consumed by DLC.

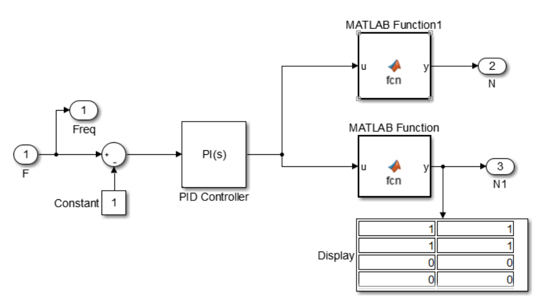

Figure 7: Resistor switching function block

3.5. Subsystem DELC

Here, in subsystem N, system frequency is compared with the reference frequency and is passed through the PI controller as shown in fig. above. The signal from the PI controller goes through a MATLAB function which has a program to calculate several resistors to be kept ON or OFF according to the power demand.

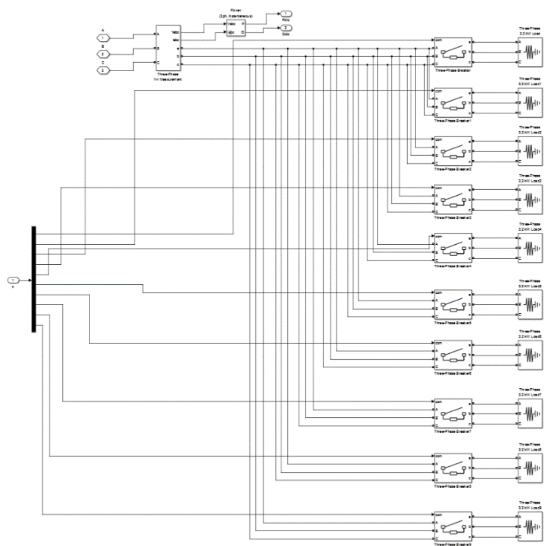

Figure 8: Detail resistive load of DELC for switching control

Here, the signal from subsystem N block is passed through de-mux, and then the signal through de-mux is passed through the command signal in 3-phase circuit breakers, which can let 3-phase breakers be kept ON or OFF according to the demand. Here, there are ten number of, 3.2 KW resistors as shown in Figure 8 above and they are kept ON or OFF according to the power demand.

4. Results and discussion

4.1. Simulation Result of ELC

After simulation, the result of the ELC controller output was seen from scope and the change in load was set by setting breaker time that is 8 sec. A load of active and reactive power changed after 8 sec was seen on the output screen. Hence comparatively active power is more than reactive power. Reactive power generation should be lower as compared to active power. This is shown in the Figure 9.

The active power consumed by the load is 10kW whereas the reactive power consumed is zero since the load is pure resistive load. From the figures we can see that surplus power that was not consumed by the consumer's load is dumped in the ballast load of the ELC, plus the generated reactive power is consumed by the ELC.

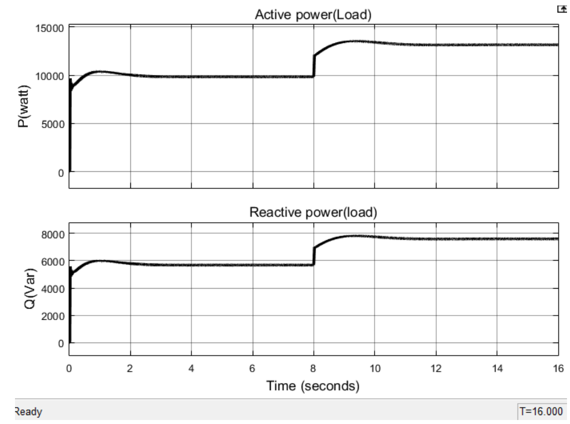

Figure 9: Active and reactive power consumptions by ELC

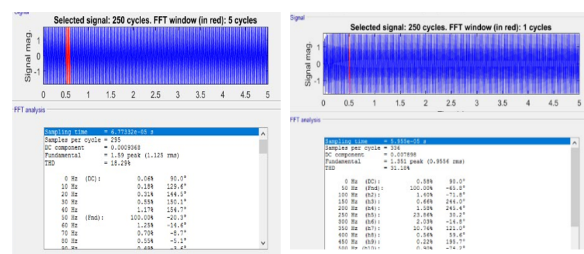

Figure 10: THD measures of Current and voltage of ELC operated system

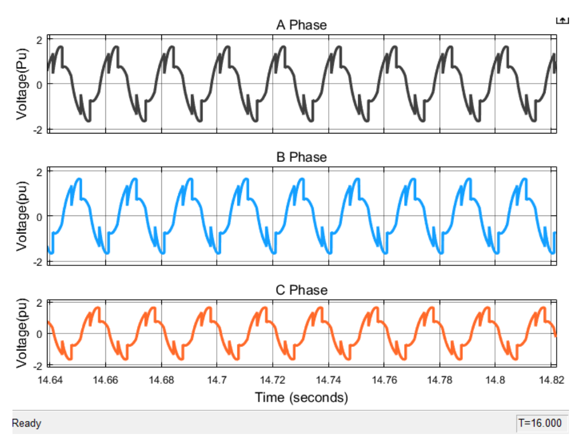

Figure 11: Chopped output phase voltages of ELC

From the above Figure 10 THD of current is measured as 18.29% and THD of the output voltage of the ELC-connected system is found as 31.16%. Due to chopping current from ELC-connected MHPP, THD was present in significant value. For better and more efficient operation THD must be minimized as far as possible and limits to below 5% range.

4.2. Simulation Result of DELC

The result shows that the waveform of output voltage is pure sinusoidal instead of conventional ELC and THD generation of the controlled system was reduced. So, using a proper logical strategy that turns on the efficient generators and which have better power quality must run more time whereas the controller whose power quality is significantly less than other controllers based on THD parameter.

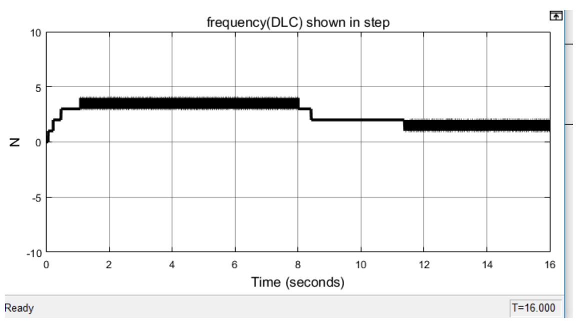

Figure 12: Step load Change (Shown by N) in DELC load

Here, from Figure 12 number of loads turned ON or OFF is seen from this diagram. Since DELC is a discrete type, the operation sequence is also a discrete phenomenon. This discrete working function is modeled by a simple MATLAB program which is then calculated by identifying how much load is turned on and how much power should be dumped for the resistor by step switching process as seen from the above figure.

Display also shown as '1' is ON and '0' signifies OFF state of several resistors to keep the power balance constant. In a discrete system, the number of resistor's ON and OFF patterns was shown in the scope of the Simulink environment.

The discrete load controller's output was shown in a stepwise pattern, which was obtained from discrete in nature. Here, the number of resistors is turned ON or OFF, according to the power demand, so there are no current and voltage chopping as sown in Figure 15. As the load increases after 8 seconds, the power flow in the DLC branch has to decrease. So, that more power is allowed to flow toward the consumer load. Hence, the action of the controller sets the output power constant by a discrete manner of control action so there aren't waveform chopping phenomena, and hence the harmonic distortion is reduced as compared to conventional ACVC ELC.

From Figure 16, THD in the operated system is found to be 5.25%, which is less than the connected system. So simply it can be concluded that in the DELC system

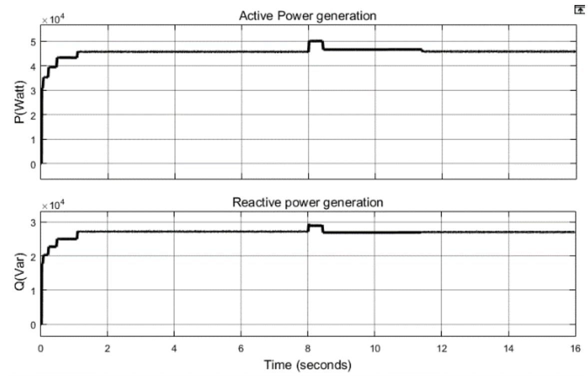

Figure 13: P and Q generation of DELC controlled MHPP system

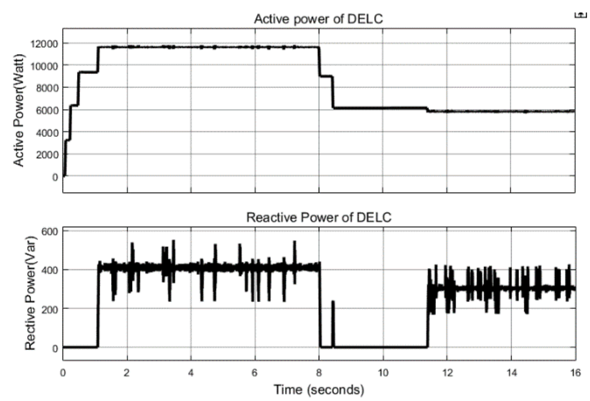

Figure 14: Active and reactive power consumed by DELC

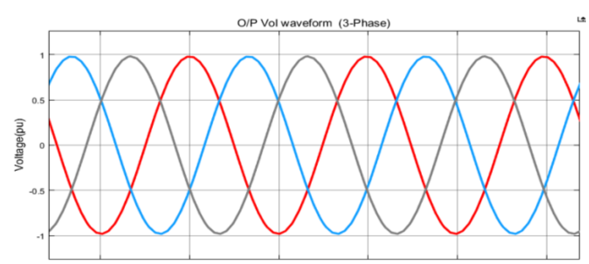

Figure 15: Three Phase output voltage of DELC

Chopping by firing angle is absent and load balance by resistor switching by turn on and off process so sinusoidal wave is purer than ELC connected system and reduced value of THD is present in DELC connected system.

5. Conclusion

In conclusion, the integration of Micro Hydropower Plants (MHPP) into power grids demands a thoughtful approach to address power quality concerns, specifically

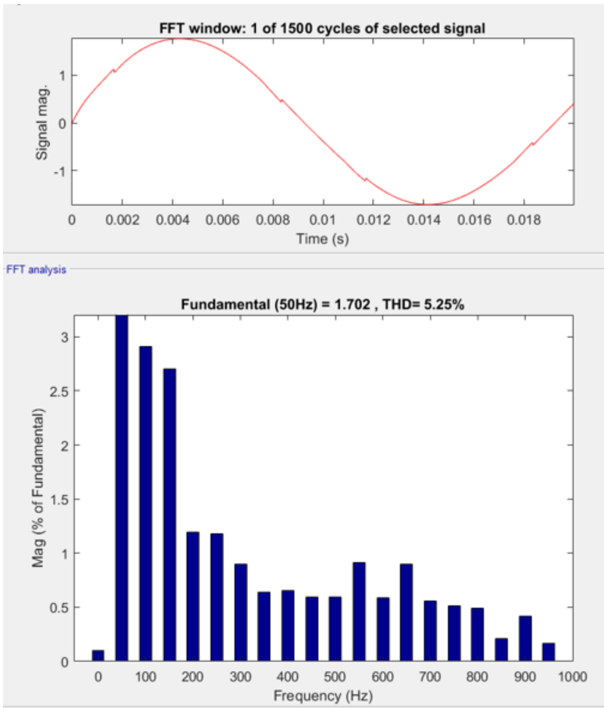

Figure 16: THD measured in the DELC system

Total Harmonic Distortion (THD). This research has presented a pioneering solution through the utilization of a Discrete Electronic Load Controller (DELC) designed for multiple MHPP.The findings underscore the significant impact of the DELC strategy in minimizing THD levels, surpassing the capabilities of conventional control methods. The optimization process for Proportional-Integral-Derivative (PID) parameters not only achieves the desired THD reduction but also ensures the stability of system operation across various fault scenarios and load variations.

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