# OPTIMIZATION AND COORDINATION OF SOURCES – HYDRO AND DIESEL GENERATION

**S. GENGATHARA, P.G.H.C.H. DHARMAKEERTHI, A. ATPUTHARAJAH, J.B. EKANAYAKE**

*Department of Electrical and Electronic Engineering, University of Peradeniya*

**ABSTRACT**

Hybrid generations are increasingly employing in power systems due to their advantageous in nature. The intermittent nature of the renewable energy sources makes them not suitable for off grid operation or in large scale grid connected operation. It was found that Sri Lanka is rich with micro hydro potential. It is required to get maximum out of this resource. A micro hydro-diesel hybrid system found to be an ideal solution with the consideration of economical and environmental factors. The proposed system is designed to operate either in islanding mode or in grid-connected mode while fulfilling continuous power demand. A control, with main and supervisory sections, was developed. The main controller in the hydro generator maintains the voltage and frequency with regulatory control while the diesel generator functioning on a droop control. The supervisory controller implemented in the diesel generator to optimize the total generation cost. In addition the supervisory controller coordinates the diesel generator on/off operations with the micro hydro generator. The proposed control system was simulated and the results show excellent performance.

## 1. INTRODUCTION

The hybrid systems are playing an increasing role in power systems worldwide. The major factors which pushing towards hybrid systems are: employability of environmental friendly renewable energy sources, effective islanded operation, reduced usage of fossil fuels, increased system stability and less unit price. Especially with renewable energy sources, the hybrid system can be controlled to supply required power without fluctuations even during islanding operation. This solves problems of fluctuating voltage and frequency. This attractive advantage attracts researcher's attention and many implementations are being undertaken to setup the hybrid systems **[1, 2, 3 and 4]**.

In Sri Lanka the annual energy demand growth is at a rate of 7-8% **[5]** mainly due to urbanization and industrialization. Statistics reveals that only 67.9% of the population had access to electricity from the national electricity grid **[6]**. This is mainly due to inaccessibility of national grid in rural areas. Recent studies **[7, 8 and 9]** shown that over 10 GW power can be extracted from renewable sources such as wind, micro hydro and biomass. Most of these identified power plants can not be connected into the grid due to inaccessibility. Further due to intermittent nature of these renewable they are not suitable for off-grid operation. However if these renewable can be operated parallel with another source as a hybrid then they become one of the ideal candidates for remote areas.

In the case of Small Hydro Power (SHP), present install capacity is around 97.5 MW **[7]**. In addition, the Ceylon Electricity Board (CEB) has issued letters of interest for about 375 MW **[10]**. However, most of the committed SHP and new SHPs are suffering due to congestion in some part of the electrical network. Further, it is identified that most of the existing SHP projects are not productive during dry months. Therefore it is required that a SHP plant must work right through the year with constant power output either in isolated or grid connected mode.

In this paper, a micro hydro-diesel hybrid system suitable for a tea factory is presented. The proposed system is designed to operate either in islanding mode or in grid-connected mode while fulfilling continuous power requirement of the factory. Hydro generator maintains the voltage and frequency with regulatory control while the diesel generator functioning on a droop control. A control, with main and supervisory control actions, was developed. Main controller controls the frequency and voltage of the system. The supervisory controller controls the diesel generator, during its operation, to optimize the total generation cost. Also the supervisory controller coordinates the diesel generator on/off operations with the micro hydro generator. Performance of the proposed system was studied using EMTDC/PSCAD. The results showed an excellent automatic and optimized operation of the system.

## 2 METHODOLOGY

### 2.1 OVERVIEW

Figure 2.1 shows the simplified circuit diagram of the studied hybrid system. Two sources represent the micro hydro and diesel generators. These were connected through short transmission line to the Factory main panel. The factory load was sectioned into three. The micro hydro generator design proved that it can be operated throughout the year. However, during the dry season due to low flow rate it cannot satisfy total factory demand. Therefore diesel generator is switched on to supply the deficit.

As the hydro generator is designed to operate continuously, frequency and voltage is regulated by its control whereas diesel generator is operated through droop control. Then optimization of the total generation cost is carried out by minimizing the diesel generator output. This is done by an supervisory controller implemented in the diesel generator. The diesel generator is switched off when its output is lower than its minimum injection value and when the hydro source can supply the total load. This shutdown process is carried out by a supervisory control added to the diesel generator.

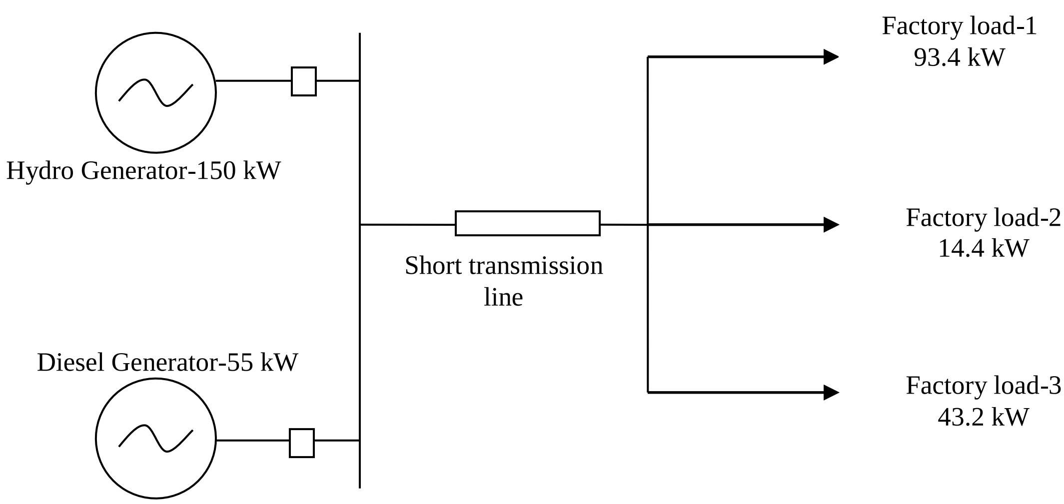


Figure 2.1: Simplified circuit diagram of micro-Grid

### 2.2 CONTROL TECHNIQUES

#### 2.2.1 DROOP WITH REGULATORY CONTROL – HYDRO GENERATOR

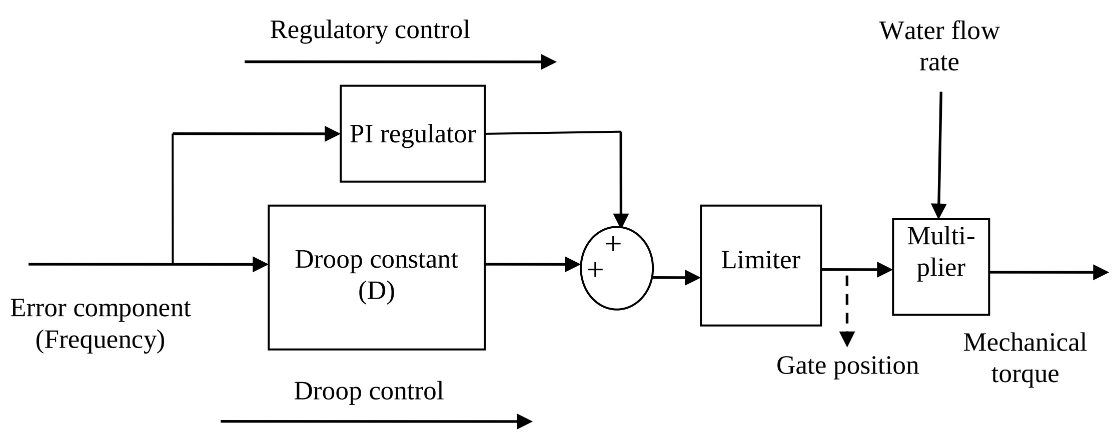


Figure 2.2a: Droop and regulatory control of hydro generator

Figure 2.2a show the control block diagram. Droop and regulatory control are used in the hydro generator **[3, 11]**. The droop control provides fast response for sudden changes and the regulatory control eliminates steady state error. Gate position varies between 0 to 1 respectively where to extremes indicates that the gate is closed or open. The effect of the water flow rate on the torque is modeled through a multiplier in this simulation. Water flow rate is varied to check the system with different operating conditions. However in practice, the water flow rate is not necessary to measure as the torque automatically varies with the flow rate.

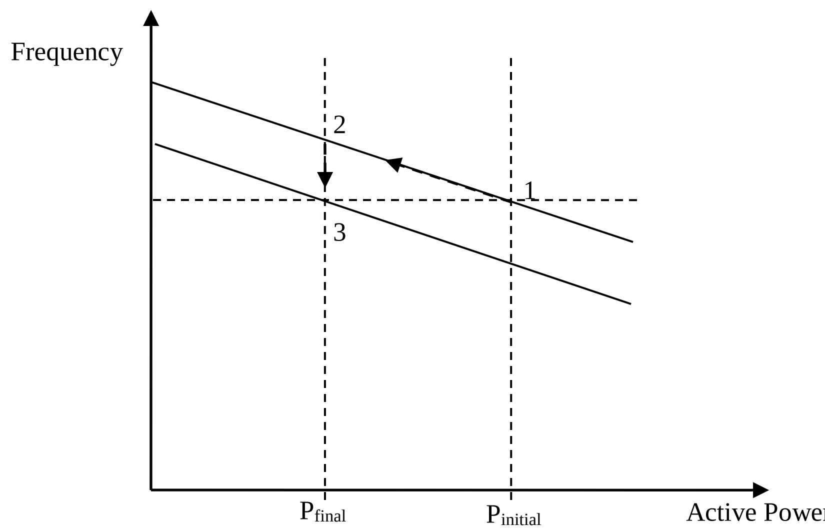


Figure 2.2b: Operation of the droop and regulatory control of hydro generator

Figure 2.2b shows characteristic graph of the droop controller. Initially the hydro generator is operated at point 1. Sudden load shading was applied as disturbance. Then the system frequency was increased and due to the fast action of the droop controller the operating point moves to position 2. Then the regulatory control regulates the frequency error signal to zero. This moved the operating point to position 3 by shifting the droop curve down.

### 2.2.2 DROOP AND OPTIMIZATION CONTROL – DIESEL GENERATOR

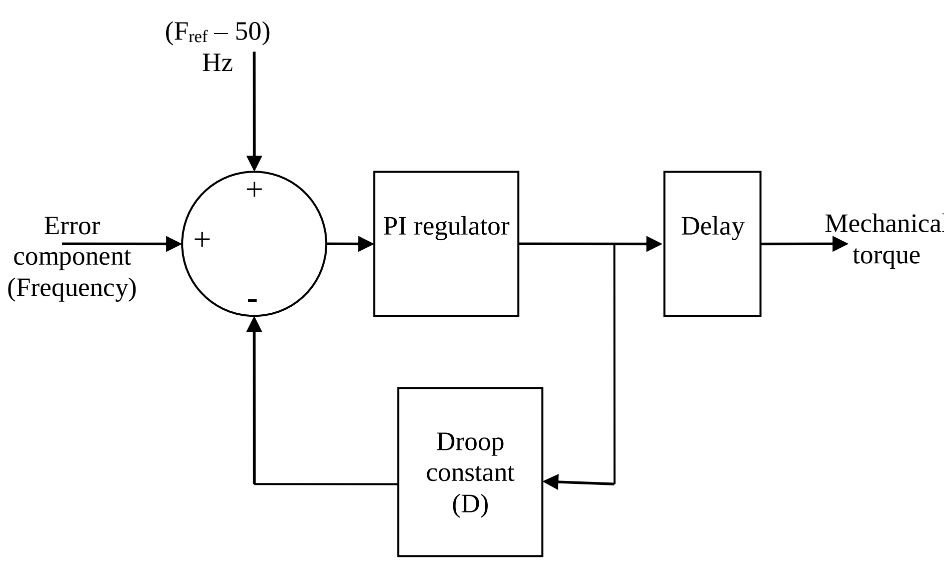


Figure 2.2c: Droop and optimization control of diesel generator

Droop and optimization control is used in diesel generator. Figure 2.2c shows block diagram of the control. Frequency error component is regulated through a PI controller to achieve the droop operation. Delay block represents the total response in the generator. However in practice, this block is not necessary as the delay already exists. A signal from supervisory control ($F_{ref}$ – 50) is added at the input block to optimize the generators operation.

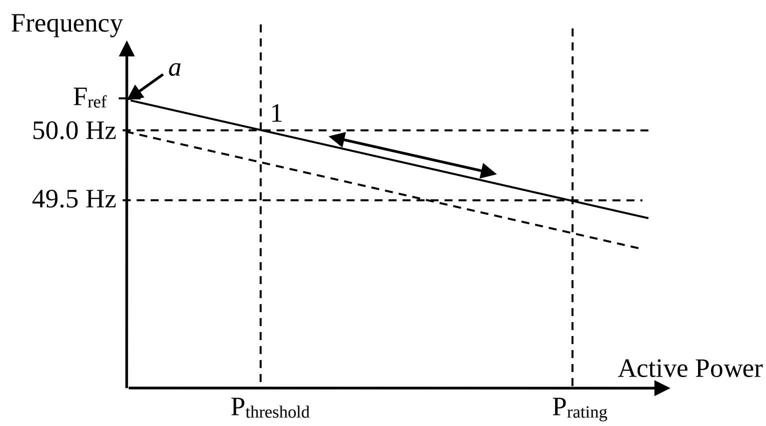


Figure 2.2d: Operation of the droop and optimization control of diesel generator

Figure 2.2d shows characteristic graph of the droop controller. When the diesel generator is started the optimization signal shifts the droop curve from 50 Hz to $F_{ref}$. This increases the output power from 0 to $P_{threshold}$ smoothly. The droop curve shifted only during the startup or shutdown periods. When diesel generator operated at point 1; any changes of load is taken by the micro hydro plant, which regulates the frequency at 50 Hz. Once the micro hydro plant hits its available power, it allows the frequency to vary within the acceptable limit. Thus increase the diesel power output to balance the load increment. This control makes sure that both of the micro hydro and diesel generators are utilizing properly to minimize the total generation cost.

### 2.2.3 SUPERVISORY CONTROL

The supervisory control coordinates both generators according to available hydro energy and load demand. Figure 2.2e shows controller to determine the status of the diesel generator. This controller monitors the status of micro hydro generator and determines on or off instant of the diesel generator. Gate position is taken from the micro hydro controller and compared with the gate threshold value. If the gate position increased above threshold then status signal becomes high and the gate threshold signal becomes low. The status signal engages the diesel generator's on/off control. The new threshold value is used to determine off status of the diesel generator. This value is calculated by subtracting threshold diesel power from the available hydropower. The available hydro power, which depends on the flow rate at that instant, is taken from a lookup table. Reducing the threshold value also prevents malfunction of the system.

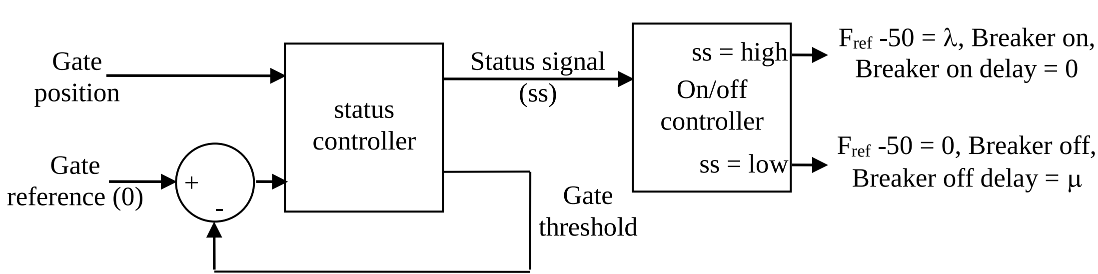


Figure 2.2e: Block diagram of the diesel generator's status and on/off controller

The diesel on/off control select the value for $F_{ref}$, set the breaker operating mode and the delay required to operate the breaker. The breaker connects or disconnects the diesel generator according to the status signal. Value of $\lambda$ is taken according to the diesel threshold power and the droop constant. Value of $\mu$ is taken according to the total system response time which bring the diesel generator to zero power injection.

## 3. SIMULATION STUDY

The hybrid system control was simulated using EMTDC/PSCAD computer simulation package. Simulation draft is shown in the appendix. The main control maintains the voltage and frequency while supervisory control coordinates both generators for their optimized operation. This simulation study was categorized in to three different cases based on available hydro power ($P_{hydro\_available}$), diesel threshold power ($P_{diesel\_threshold}$) and load demand ($P_{load}$). They are:

| Cases | Criteria | Generator scheduling |
|---|---|---|
| 1 | $P_{hydro\_available} > P_{load}$ | Only hydro operation |
| 2 | $(P_{hydro\_available} + P_{diesel\_threshold}) > P_{load} > P_{hydro\_available}$ | Diesel kept at its threshold power and hydro was changed according to the load requirement |
| 3 | $P_{load} > (P_{hydro\_available} + P_{diesel\_threshold})$ | Hydro kept at its available power and diesel was changed according to the load requirement |

Table 3a: Categorizes of generator operation and scheduling for the simulation study

### 3.1 CASE 1

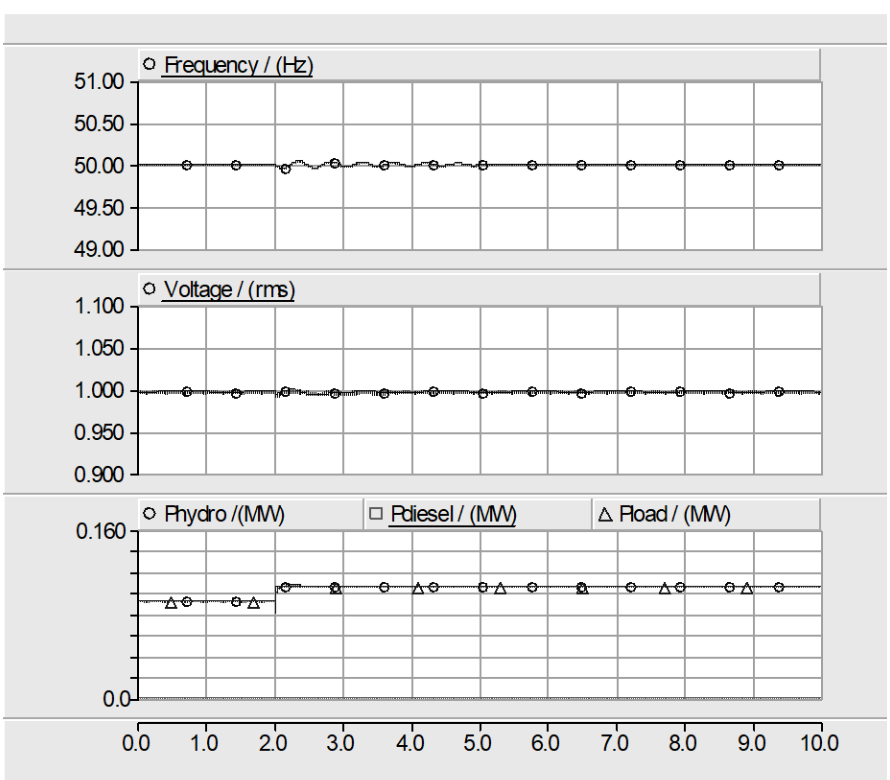


Figure 3.1: Variation of frequency, voltage and power for a sudden load change

Initially the load resistors were set to produce 93.4 kW to the system and an extra load of 14.4 kW was connected at 2 seconds of the simulation study. In this case the flow rate was taken as 0.85pu, which correspondent to the available hydro power of 127.5 kW. Therefore here the diesel generator was shutdown and only hydro generator was operated (case 1) to supply the power to factory.

Simulation results for this case are shown in Figure 3.1. Frequency and voltage was maintained at its rated values. Diesel generator power was zero as it was switched off and hydro generator supplies the load demand. Therefore it shows excellent performance of the control for this case, which includes a sudden change of the load.

### 3.2 CHANGE OVER FROM CASE 1 TO CASE 2

Initially the load resistors were set to produce 93.4 kW to the system and an extra load of 43.4 kW was connected at 2 seconds of the simulation study. In this case the flow rate was taken as 0.85pu, which correspondent to the available hydro power of 127.5 kW. It shows that the system is moved from case1 to case2. Therefore in this case initially only hydro generator was operated (case 1). Then after increase the load, the diesel generator was switched on and kept it at threshold operation while hydro generator was operated not at its available power but to balance the load demand.

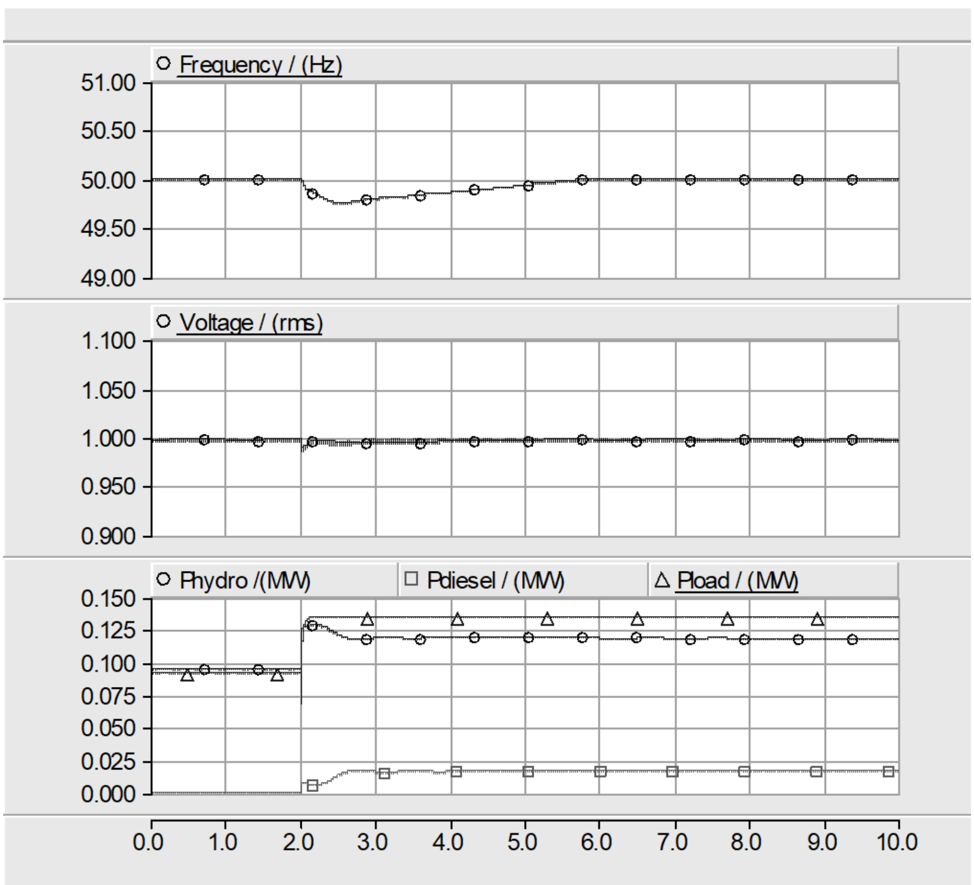


Figure 3.2: Variation of frequency, voltage and power for a sudden load change during changeover took place from case 1 to case 2

Figure 3.2 shows simulation results. Initially only hydro is operating according to the load demand. At 2 seconds of this simulation an extra load of 43.4 kW was connected thus switched on the diesel generator. Voltage was maintained at its rated value. The frequency regulatory control slowly brought it back to the normal value. At steady state the diesel generator injecting its threshold power. Therefore it shows very good transient and steady state performance of the control when the load was suddenly changed, which change the system from case 1 to case 2.

### 3.3 CHANGE OVER FROM CASE 2 TO CASE 3

Initially the load resistors were set to produce 137 kW (case 2) to the system and an extra load of 14.4 kW was connected at 2 seconds of the simulation study. In this case the flow rate was taken same as in case 2. Therefore the system moved from case2 to case3 at 2 seconds. So initially the diesel was operated at its threshold and hydro was operated to balance the load demand (case 2). After increase the load, the hydro was injecting its maximum available power while the diesel was operated to supply the rest of the load (case 3).

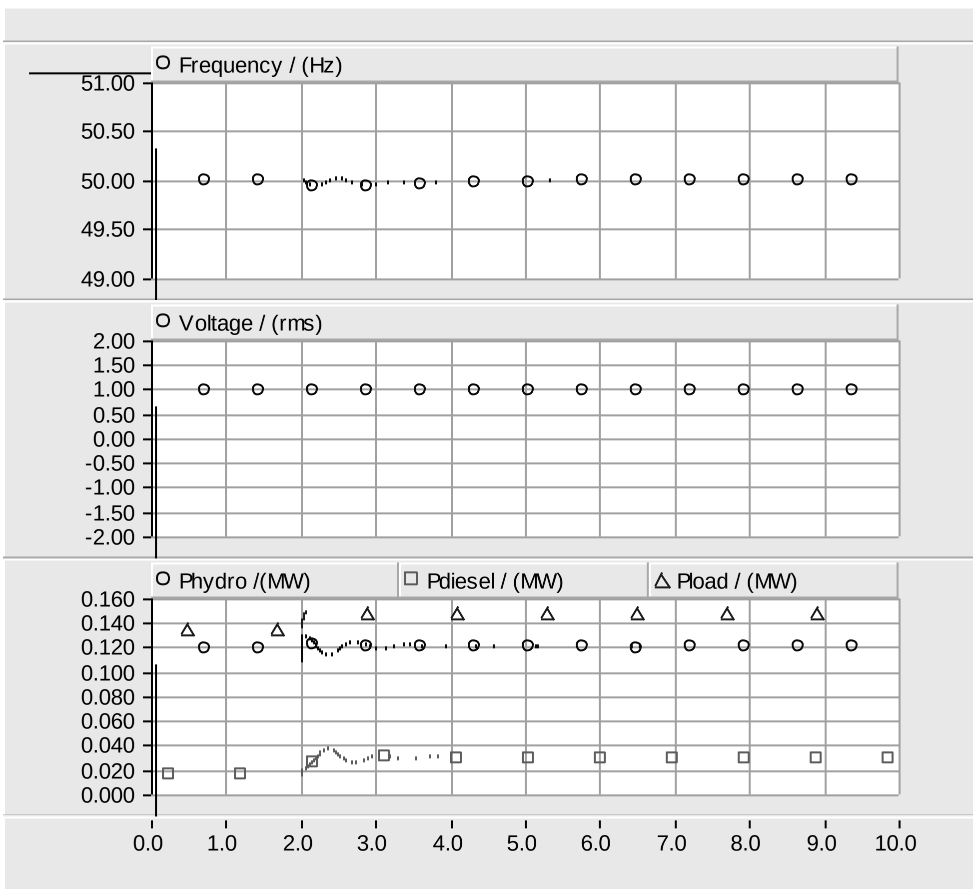


Figure 3.3: Variation of frequency, voltage and power for a sudden load change when changeover took place from case 2 to case 3

Figure 3.3 shows simulation results. Initially diesel was operated at its threshold power while hydro was balancing the load demand (case 2). At 2 seconds of this simulation an extra load of 14.4 kW was connected thus switched on the diesel generator this make the system moves into critically case 3. Voltage was maintained at its rated value. The frequency regulatory control maintain at it rated. At steady state the diesel generator injecting more than its threshold power. And the hydro is injecting the maximum available power. Therefore it shows very good transient and steady state performance of the control when the load was suddenly changed, which change the system from case 2 to case 3.

## 4. CONCLUSION

Literature survey concludes that electrification of rural areas by expanding the grid is an expensive solution in Sri Lanka. As an alternative small scale hydro power plants are in operation in many parts of the country. However many installed micro hydro power plants proven that hydro power plant itself is not a good solution.

This research introduced a hybrid solution with novel control technique to coordinate two generators. A primary control was proposed to regulate frequency and voltage. In addition a supervisory control is developed to optimize the total generation cost. The proposed system was simulated for three cases such as only micro hydro operation, diesel operated at its threshold while micro hydro balancing the load demand and finally micro hydro operated at its available maximum while diesel balance the load demand. In all three cases, results show excellent performance of the proposed system. Therefore this study conclude that the proposed "micro hydro – thermal" hybrid system with the novel control system can provide more reliable, optimized and autonomous power plant operation.

From the national development point of view, micro hydro projects can be enhanced with this hybrid control technique to improve their performance. This will create avenue for utilizing available hydro resources to generate power in remote areas.

## 5. ACKNOWLEDGMENT

The authors would like to thank Mr. Sunith Fernando, Director of Resource Management Associates (Pvt) Ltd and Head of the Department of Electrical and Electronic Engineering University of Peradeniya for their support.

## 6. REFERENCES

1. Y. Zoka, et al., "An interaction problem of distributed generators installed in a micro grid", IEEE International conference proceedings on Electric Utility Deregulation, Restructuring and Power Electronics, April 2004, Pages 795 – 799.
2. R.H. Lasseter, "MicroGrids", 2002 IEEE Power Engineering Society Winter Meeting Conference Proceedings, New York, NY, vol. 1, pp. 305- 308.
3. A. Arulampalam, et al., "Automated control technique to coordinate microgrid sources – Grid connected and islanded operation", International journal of distributed energy resources, Vol. 91, No. 9, September 2004. Pages 503 – 523.
4. Barsali S., et al., "Control Techniques of Dispersed Generators to Improve the Continuity of Electricity Supply", Power Engineering Society Winter Meeting, 2002, IEEE, Vol. 2, 27-37 January 2002.
5. Ceylon Electricity Board, "Long Term Transmission Development Studies (2004-2013)", Transmission Planning Section, Transmission and Generation Planning Branch, Transmission Division, CEB, Sri Lanka, October 2004, Chapter 1.
6. Ceylon Electricity Board, "Long Term Generation Expansion Plan (2005-2019)", Transmission and Generation Planning Branch, Transmission Division, CEB, Sri Lanka, November 2004, Chapter 2.
7. DFCC Bank, "Final report on Technical assessment of Sri Lanka's renewable resource based electricity generation", Renewable Energy for Rural Economic Development project, Sri Lanka, Project No. 108763-0001, March 2005, Chapter 1, Pages 1 – 5.
8. Romesh Dias Bandaranaike, "Grid connected small hydro power in Sri Lanka: the experiences of private developers", International conference on accelerating grid based renewable energy power generation for a clean environment, March 2000, Pages 1 - 5.
9. Wind Energy Resource Atlas of Sri Lanka and the Maldives, National Renewable Energy Laboratory, USA, http://www.nrel.gov/wind/past_pubs.html.
10. DFCC Bank, "Management Discussion & Analysis - Sector Review", Annual report of DFCC bank 2004/05, Review 2005, Pages 13 -18.

11. P. Kundur, “Power System Stability and Control”, Book, McGraw-Hill Inc., 1994, ISBN 0-07-035958-X, Chapter 11, Pages 581 - 691.