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UNDER FREQUENCY LOAD SHEDDING MODEL WITH OVERLOAD PROTECTION

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***Abstract*— Load-damping characteristic models the load response to the frequency deviation, which has important impact on system frequency response. The load-damping coefficient is normally considered as a constant, obtained from operational experiences in large-scale power systems or from detailed load models in isolated power systems. An industrial isolated power system for aluminum production driven by coal-fired power and large scale wind power is studied in this paper. Since the electrolytic aluminum load is driven by direct current, it is one type of voltage-sensitive load and does not respond to the frequency deviation. This paper proposes a load-damping characteristic control method for such isolated industrial power system with voltage-sensitive load. To decrease the maximum frequency deviation during transient process, a time-varying load-damping coefficient control scheme is presented. Simulation is done on real-time digital simulator (RTDS) and the results verify the effectiveness of the proposed control method. Further, a circuit model has been proposed using ATMEGA 328 whose program is written in 'c' language and flashed in it using a driver software provided by Arduino ISP via USB interface.**

***Index Terms*— Load damping, Real Time Digital Simulator(RTDS), ATMEGA 328, Arduino ISP.**

I. Introduction

In power system, blackouts have been the most problem occur in the interconnected grid which results in large loss. Power system blackout is one of the major challenges of electric utilities in the world such as blackout of Greece, Italy, North America, Sweden and Denmark. However, in recent years this phenomenon has considerably increased based on the frequency and the severity of this problem. This may be due to the consequence of new regulations and restriction restricted by power system deregulation. In fact, it is not possible to completely prevent these power deficiency occur. However, proper monitoring, control and protection schemes, frequency and the severity of this phenomenon occur may be reduced. Under frequency load damping (UFLS) scheme is proposed to enhance the reliability of power systems to against system failure and fault occur. This scheme is classified as protection scheme or system protection scheme. System protection scheme is defined as protection strategies designed to detect a particular condition which is known to cause failures to the power system and prepare some kind of predetermined action counteract the observed condition in a controlled manner. System protection scheme is specially designed to detect abnormal conditions at the same time take predetermined corrective action, other than the isolation of faulted element, to preserve system integrity and provide acceptable system performance.

The objective of using the protection scheme is to increase power system reliability especially in term of security during extreme contingencies and to improve power system operation as well. Under frequency load damping (UFLS) scheme is one of the most commonly used as a protection schemes. Under frequency load damping (UFLS) scheme is conventionally designed to preserve the balance power in the island during fault occur. Under frequency load damping (UFLS) is a very important approach to prevent frequency decline. It should have capability not only to damp load under different operating modes when local systems are connected to the main systems, but also capable to maintain the frequency stability when local systems are islands. The primary method to bring back to the nominal frequency level is to damp amount of load. In power systems protection scheme, the frequencies are widely used as a setting in UFLS design. Under frequency load damping (UFLS) must be performed quickly to arrest power system frequency decline by decreasing power system load to match available generating capacity. Extreme frequency decline can occur within seconds.

An automatic under frequency load damping (UFLS) scheme is applied to restore the system frequency to an acceptable level following a major system emergency which can cause a generation deficiency. In conventional under frequency protection design the only measured parameter of the system involved in decision making is frequency. Excessive frequency decline may cause damage to the equipments of power system particularly turbine blades in power plant at frequency below 47.5Hz. During normal operation of power system the amount of generation is equal to the amount of demand. Whenever the faults occur, either the amount of generation is decreases or the amount of load is suddenly increases, the balance of power is violated and the frequency falls at the predetermined threshold the portion of the load will be damp in a few steps to equalize the amount of demand and generation to prevent the system collapse. The loads to be damp in this system are damp constant load feeders and are not selected adaptively. In the other hand, these systems always drop the same load regardless of the location of disturbance.

In this project rate of change of frequency is proposed to enhance the adaptability of under frequency relays. By using this load damping method, fast reactions could be obtained for major system failures. Neuro-fuzzy under frequency load damping scheme can prevent complete system blackouts in the case of large or small disturbance. In other word, Neuro-fuzzy under frequency load damping scheme is specially designed to counter any kind of in coming disturbance applied. Rate of change of frequency, df/dt is the indicator to detect the magnitude of disturbance or faults. The rate of change of frequency df/dt is an instantaneous indicator of power imbalance and is presently used with the frequency function to provide a more selective or faster operation. To make the rate of change of frequency df/dt as power deficiency indicator additional information about the system is required such as voltage, spinning reserve, load and etc. Such information may be communicated to the relay.

There are three types of the under frequency relays available for load damping scheme purpose. They are electromechanical relays, solid-state relays and digital relays. The purpose of the under frequency relay is for monitoring the frequency of an alternating current power line and protect the system by giving signal whenever the frequency drop below predetermine value for a specific length interval. The frequency of grid system must be maintain at 50Hz, if the frequency drop below nominal value the protection scheme must be initiated in order to maintain its generator on line even at low frequency. Frequency drop in power line may take several steps to measure. One of the methods is by using oscillator, the frequency which is substantially higher than the nominal frequency being measured, and counting the number of pulses from the oscillator during the period. When the line frequency decrease, the period will correspondingly increase, and therefore a high number of oscillator output pulse will be obtained. The objective of the invention of under frequency relay is to provide method of detecting an under frequency condition on an alternating current power line including the step of sensing by means of electrical circuit. The frequency of grid system must be maintain at 50Hz, if the frequency drop below nominal value the protection scheme must be initiated in order to maintain its generator on line even at low frequency. Frequency drop in power line may take several steps to measure. One of the methods is by using oscillator, the frequency which is substantially higher than the nominal frequency being measured, and counting the number of pulses from the oscillator during the period. After the power deficient has been cleared, the amount of the power generation and the power demand is approximately the same. Therefore the frequency of the system will bring back to the acceptable level because the power imbalance is proportional to the frequency deviation.

II. OPERATING PRINCIPLE

The implementation has been done with neural network and modified Ga methods. In GA, encoding trees are reconstructed as given in further sub sections.

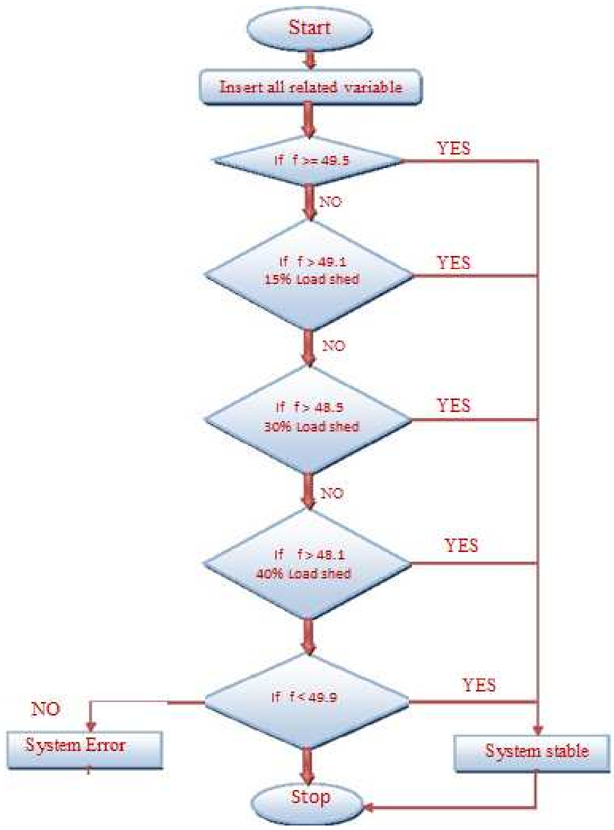


Fig. 2.1 Flowchart for Design Load Damping System

A) Design Of Controllers with Load Damping Fundamentals

i. Active Power and Frequency

During normal operation f_oa power system, the total mechanical power input to the system generators is equal to the sum of the connected loads plus all real power losses [13] . If for any reason, the balance of Generation and loads is disrupted, operating frequency of the system would change according to (1).

$$2H \frac{df}{dt} = Pm - Pe \quad (1)$$

Where, H is the inertia constant
$f$is the generator frequency in pu
$P_m$is the generator mechanical power in pu
$P_e$is the generator electrical power in pu

In general, power system loads are dependent on both voltage and frequency. To be able to compute exact amount of system load, this dependence should be considered. Power system voltage is a local parameter and its value is not usually known precisely for each remote system bus. Despite of voltage, system frequency is a general parameter and is almost similar at all points of a power system [14]. The frequency dependent characteristic of composite load may be expressed as (2):

$P_e = P_L + d\Delta f$ (2)

Where, d is load reduction factor

P_L is the load power in pu

ii. Final Frequency

According to (1) and (2) if a power system encounters with an overload case, then frequency of the system begins to decline. At the same time, system load which is dependent on frequency by factor d is reduced as well. If no other action is performed, eventually system settles at a final frequency at which the amount of generation reduction would be equal to reduction of system loads [13].

$\Delta P_m = d\,\Delta P_e$ (3)

The final frequency will be:

$$f\infty = fo - \left\{1 - \frac{lo}{(1+lo)\,d}\right\} \quad (4)$$

Where, f is the initial frequency

f∞ is the final frequency

lo is the amount of overload in pu

iii. Minimum Allowable Frequency

All of the power system apparatus are made and designed for nominal frequency. Power plant auxiliary services are more demanding in terms of minimum allowable frequency. Steam turbine is the most sensitive equipment against frequency drops. Continues operation of steam turbines should be restricted to frequency above 47.5 Hz. Frequency falls below 47 Hz must be avoided. In fact, every commercial turbine can sustain up to 10 contingencies at 47 Hz just for one second without being jeopardize [4].

B) Conventional Method

i. Load amount to be Damp

For a system overload the amount of load which must be damp is determined based on the minimum allowable frequency and the amount of overload. The minimum allowable frequency could be considered as 47 Hz instead of 47.5 Hz in load damping schemes design, if the system dispatch center can increase the generation by governors quickly. Total amount of the load which must be damp to cover the maximum anticipated overload, is obtained from [5] :

$$LD = \frac{\frac{L}{1+L} - d\left(1 - \frac{f}{50}\right)}{1 - d\left(1 - \frac{f}{50}\right)} \quad (5)$$

Where, LD is total load which must be damp

f is permissible settling frequency

Example 1:

Generation = 10000MW Load = 10500MW f_o = 50 Hz H_{sys} =0.17

df/dt = - (50*(1.05-1.0)) / (2*0.17)

= - 0.73529 Hz

Then f = 49.2647 Hz

By Using This formulae

$L=(P_L - P_G) / P_G$ =(1.05-1) /1= 0.05

Load Damp is

LD=((0.05/1.05) – 0.8(1-(49.26/50)) / (1- 0.8(1-(49.26/50)) = .0372 pu

= 372 MW

ii. Neural Network Approach

The procedure to be followed in this case involves four main steps.

Identification of input / output relevant variables

Data set generation

Design of the NN

Performance evaluation of the neural nets

The identification of the variables that are going to characterize a given operating scenario is an important step for a successful application of these techniques. Sometimes a pre-processing stage is needed to select the most relevant variables to be used as inputs of a NN. In this work, we decided by just selecting a set of meaningful variables have been used as inputs of the NN. Actual real power generation, Active load generation level prior to disturbance, Amount of active load being damp, Percentage of exponential type Loads being damp. These variables provide the NN with valuable information, such that it can make the needed assessment with respect to how much the generation-load imbalance has been corrected and the influence each load type has on the resulting frequency response.

The replication of a given power systems response through any machine learning technique, like a NN, can only be accurate if the data used to train these structures describes with enough coverage and quality the different operating conditions. Optimally. This data set would include all possible system scenarios; however this would require unrealistic hours of computational time. Therefore the objective of the data generation stage is to capture the breadth of the system operating conditions and behavior, while limiting computational and engineering efforts. This data set includes the data used for training a NN and the test data for evaluation purposes.

The first step in the design of a NN is to determine an architecture that will yield good results. The idea is to use the simplest architecture while maximizing performance. Usually, NN architecture is determined [5] based on subjective assessment on the part of the engineer. Within this work it was concluded after a few trials that architecture of 2 hidden layers, the first with 14 nodes and the second with 10 nodes, was best suited for this application. An LEVENBERG – MARQUARDT Back Propagation technique was used to train the NN[11] . This consists of the same routine as typical back propagation with the exception that instead of one learning rate for all the NN nodes, a learning rate was assigned to each of the nodes in order to speed up convergence. The activation function used within this work was a hyperbolic tangent function and the inputs were normalized to have a mean of zero and a variance of one.

In order to get an idea for what kind of performance is to be expected from NN architecture, a preliminary evaluation is needed of its capabilities. The “training set” data, typically composed of % of the OPs from the overall data set, is used to teach the NN and give a relative inclination as to its suitability for that particular application. The "test set," which is comprised of the remaining data, is used to evaluate the prediction capabilities and generalization performance of the structures. If the training set provides good results, in terms of accuracy, and the test set does not, this generally indicates over-fitting in the learning stage and/or that the current NN structure is too complex and needs to be simplified. On the other hand if the training set and test set provide comparable results, but not satisfactory ones regarding the user this generally implies that a more complex structure should be tried. Once desirable results are attained from both the training and test data, a comparative evaluation can be made with the Conventional Method.

III. PARAMETERS AND MODELS

A) Neural Network Architecture

There are 3 layers in the network, 3 input variables, 1 hidden layer, 2 hidden layer neurons, 1 output layer neuron. Number of neurons in a hidden layer can approximately be determined from the formula

$$H = T / \{5(N+M)\}$$ where,

H= number of hidden layer neurons.
N= size of the input layer
M= size of the output layer
T= size of the training set

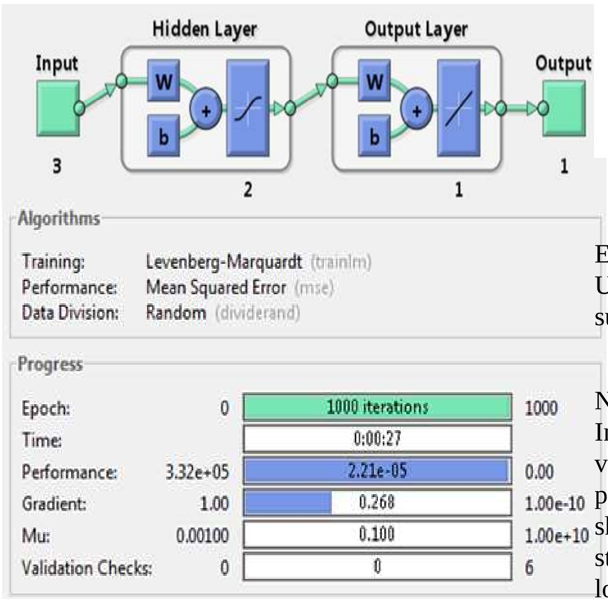


Fig. 3.1 Neural Network Design

B) GA Based Tools

The GA is used in this paper for three reasons: 1) the GA can approach the global optimum; 2) the GA can deal with inequality constraints efficiently; and 3) the GA does not need to calculate the derivatives of and which are implicit and cannot be formulated in closed forms. In particular, and cannot be handled by traditional gradient-based optimization methods. Inequality constraints are treated more efficiently by using the penalty function to deal with (3), (4), (7), and (8). All operands in GA are real numbers rather than traditional binary bits. Especially, this paper proposes a novel tree-encoding method to handle (5) efficiently.

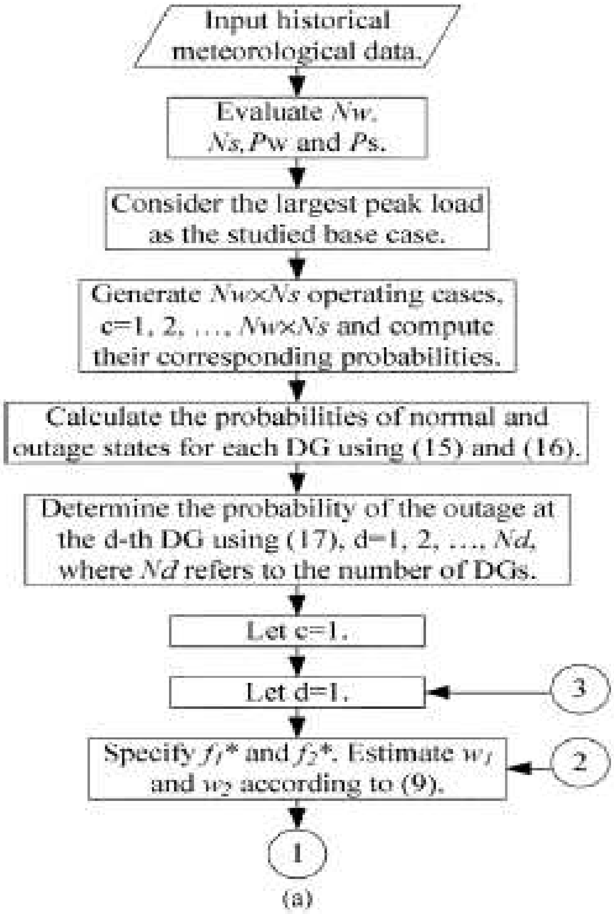


Fig. 3.2 Flowchart of GA Process

Exactly how the UFLS scheme in large power systems and the UFLS scheme in micro grids differ from each other is summarized as follows.

1) In large power systems, engineers may consider N-1 and N-2 outages in setting the parameters of 81 L relays. In micro grids, only an N-1 outage is considered because the voltage is low and most of the loads are insensitive. 2) In large power systems, the frequency that triggers first-stage load shedding is high (e.g., 59.4 Hz) because the power-quality standard is strict. In micro grids, the frequency for first-stage load shedding is low (e.g., 58.2 Hz) because most of the loads are insensitive.

2) The total number of load-shedding stages is large (e.g., 12), and the difference between the frequencies in two consecutive stages is small (0.5% 60 Hz) in large power systems. However, the total number of load-shedding stages is small (e.g., 4 6), and the difference between the frequencies of any two consecutive stages is large (1% 60 Hz) in the micro grids. This difference is owed to the limited number of loads at the candidate feeders in a small micro grid.

3) The "maximal shed load," which must be defined for large power systems, is usually 30% of the system peak

load. The shed load at each stage is the "maximal shed load" divided by the number of stages. However, in a micro grid, the shed load at the first stage is expected to be the largest among all stages and the shed loads at the subsequent stages decrease gradually to increase the efficiency of the UFLS scheme.

4) In large power systems, generations from most of generating units are assumed to be according to the load profile.

Restated, a scenario with the largest peak load is considered to be a base case for determining the parameters of 81L relays. In addition, the load patterns in other scenarios are assumed to be proportional to those in the base case. Therefore, the shed loads in other scenarios are only fractions of those obtained in the scenario with the largest peak load. However, this assumption is inapplicable in the micro grid, because of the intermittent and meteorological data-dependent nature of renewable energies. 6) The inertias of the generating units are large in a power system, while those of the power inverter-based renewables impact the frequency in the micro grid to a lesser extent. Relay engineers consider the following factors when designing the parameters of an under frequency relay [2]: 1)power system operational requirement (maximal amount of shed load); 2) parameters of the 81L relay (frequency of first-stage shedding, total number of load-shedding stages, and time delay at each stage); and 3) shed amount at each stage. As described before, the frequency of first-stage shedding depends on the power frequency quality that is requested by customers. The time delays set in relays in small power systems are generally ignored. Hence, the total number of load-shedding stages and shed amount at each stage must be evaluated.

This work makes the following four assumptions:

1) If the micro grid is connected to the main power system and a large disturbance occurring in the main power system negatively impacts the micro grid, a static switch located at the point of common coupling disconnects the micro grid from the main power grid and no shed load in the micro grid is required;

2) If the micro grid is connected to the main power system and a disturbance occurs in the micro grid, the frequency in the micro grid remains stable and no shedding load in the micro grid is required.

3) If the micro grid is islanding and loss of the main generation source causes the frequency to decrease, UFLS relays serve the sole special protection scheme in the micro grid;

4) The utility owns the main grid but not the micro grid. Parameters of the UFLS relay determined by the decision maker in the micro grid do not need to coordinate with those in the main grid.

IV. SIMULATION RESULTS

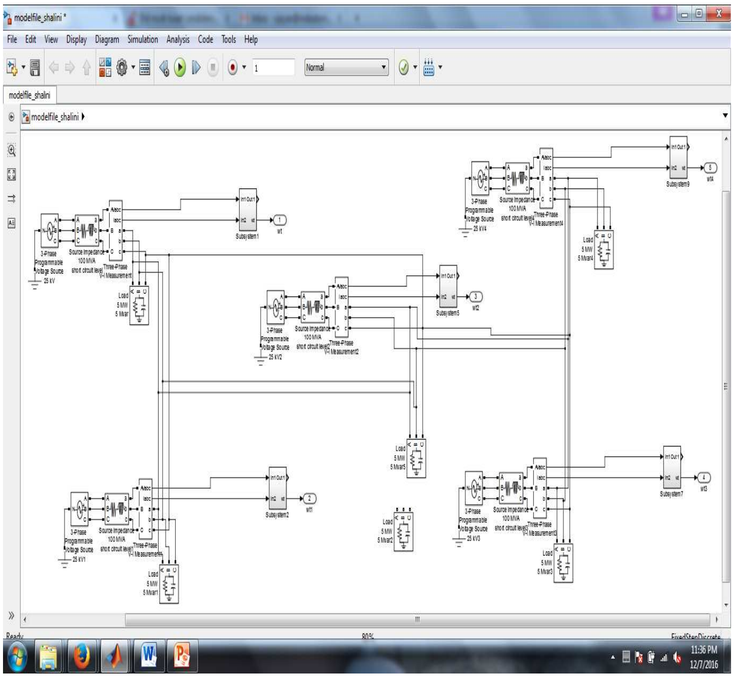


Fig. 4.1 Overall model

The Simulink model consists of 5 distributed generated and its associated loads. The frequency is measured using PLL designed using FIR filter shown in next snapshot. Loads are of linear and inductive and capacitive loads.

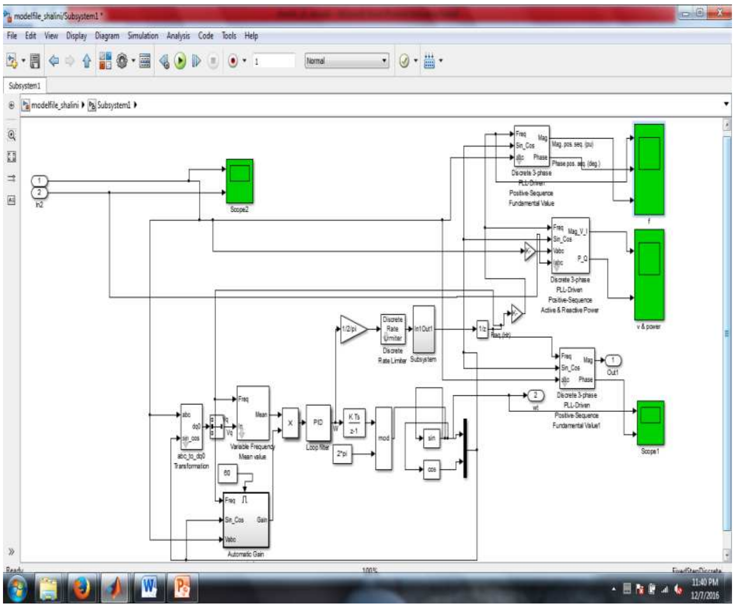


Fig. 4.2 PLL Based Frequency Measurement Setup

The measurement systems consists of a abc to dq conversion, followed by a PID controller and a low pass filter. The filter has been designed with FIR filter coefficients with cut off frequency around 50Hz. All other remaining scopes shows other parameters such V, I , P (real) and Q (imaginary) respectively.

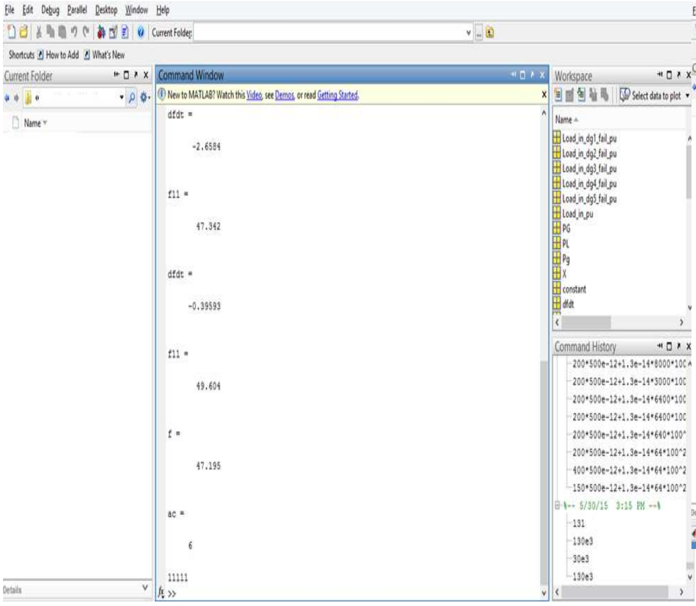


Fig. 4.3 Load damping decision is 11111 ,when the input is 130kw load demand.

Neural network classification output

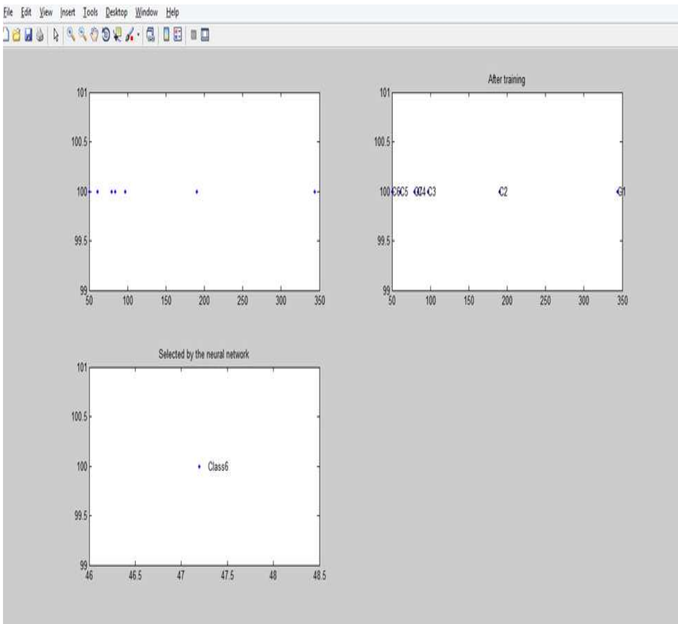
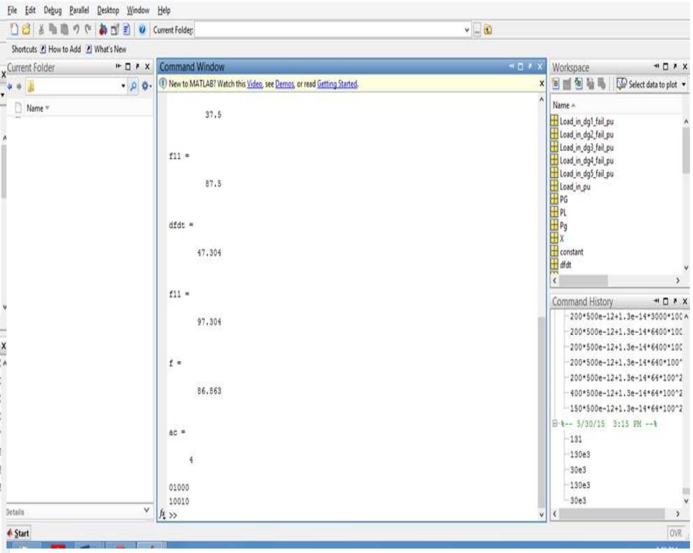
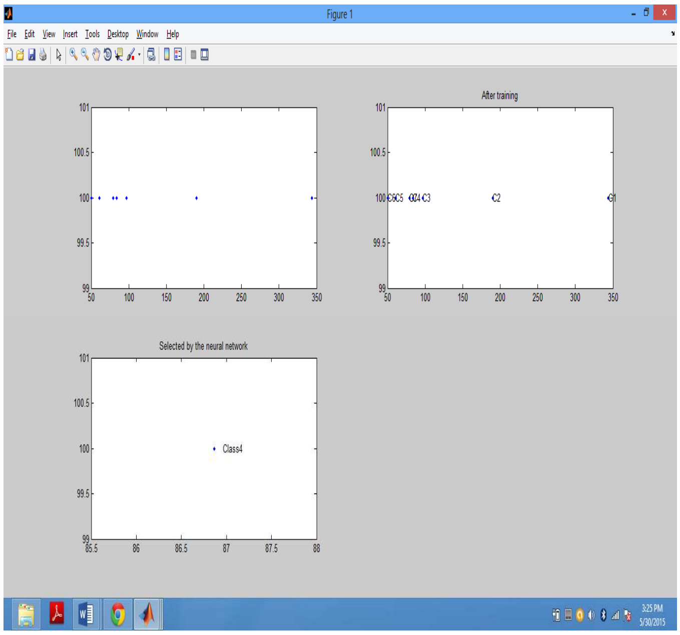


Fig. 4.4 The frequency of the system classified by the GA and based on that frequency load damping is decided. The above case needs all the loads to be used.

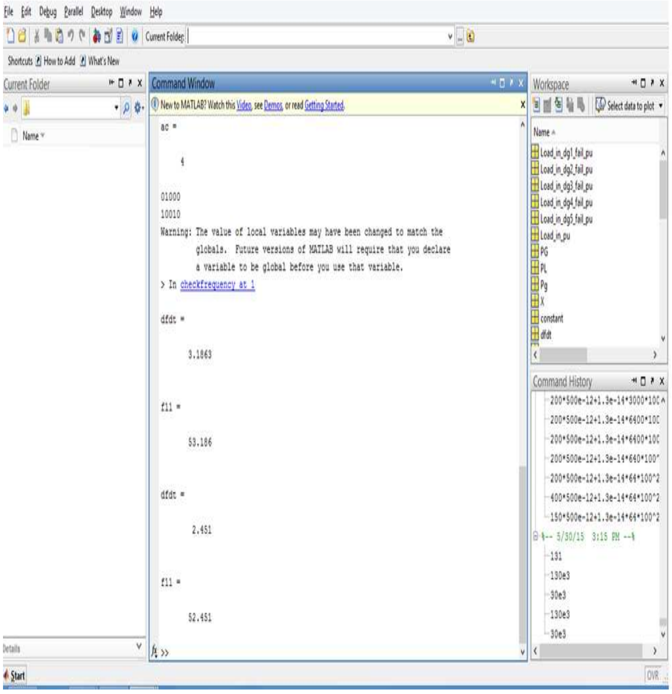
The frequency is correct after the LOAD DAMPING operation, while operating at state 11111, that means all the generators are switched ON, the frequency turns out to be 50.17.

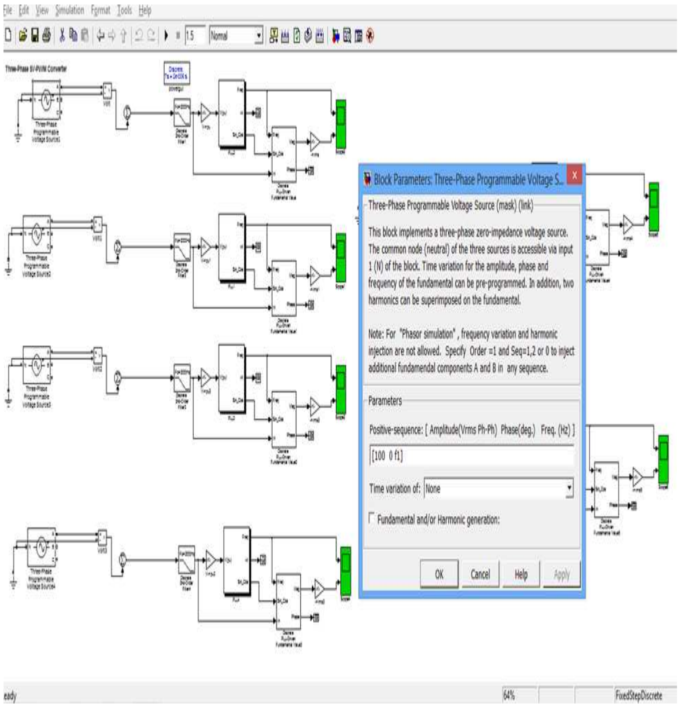


The above snapshot shows the frequency is shifted to 86.863 Hz,when all the generators are operated. To maintain the frequency, it is decided to use the 01000 or 10010 LOAD DAMPING combination. This means that G1,G3,G4,G5 are off and only G2 is functioning. The second case is G1 and G4 only are operated. And other generators are off.

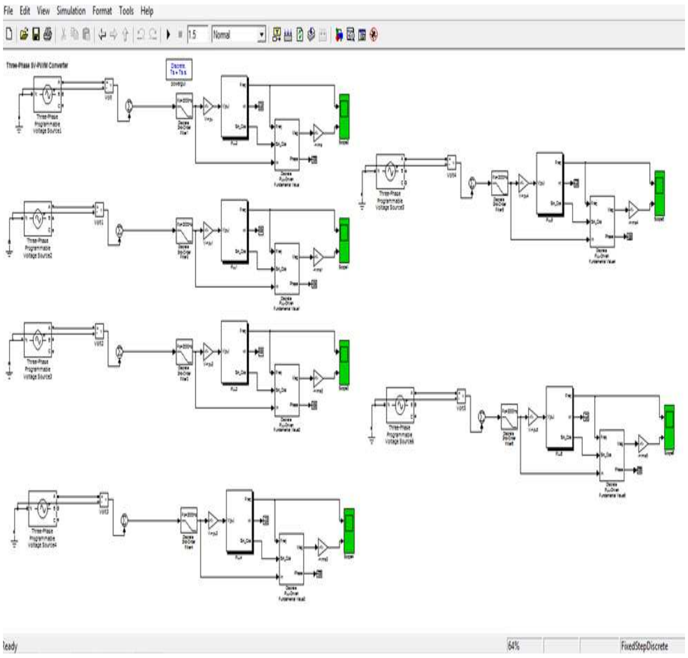


The above figure shows the frequency of the system classified by the Modified GA based on that frequency load damping is decided. The above case needs all the generators to be used. The frequency is correct after the LOAD DAMPING operation, while operating only G1 and G4, the frequency turns out to be 52.451. The snapshot is given below.





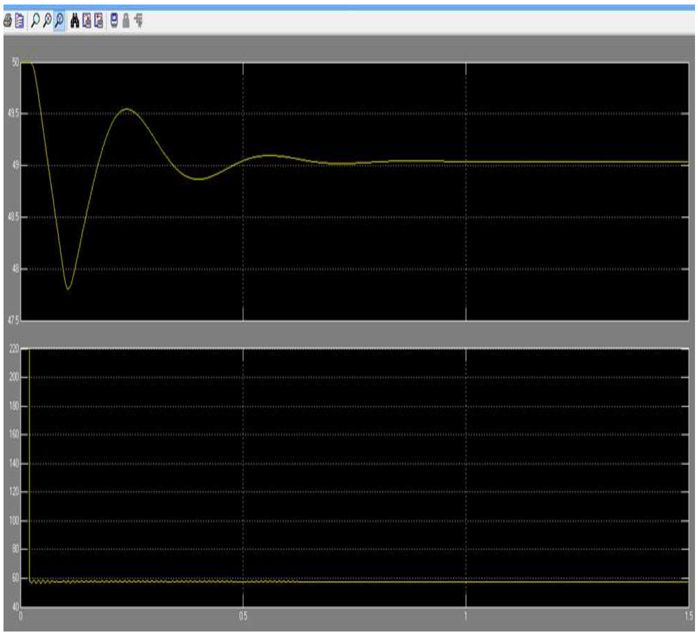
Simulink Model To Find The Instantaneous Frequency



The above Simulink model consists of a PLL after a low pass filter, detects the instantaneous frequency of the various generators. At load side a combined effect is observed. To create the variable frequency , a programmable voltage source is considered and its frequency is varied to check the performance of the PLL in detecting the frequency.

The above snapshot, conveys a matter, that f1 is the frequency from the generator 1. The same is measured and shown as a plot with respect to time.

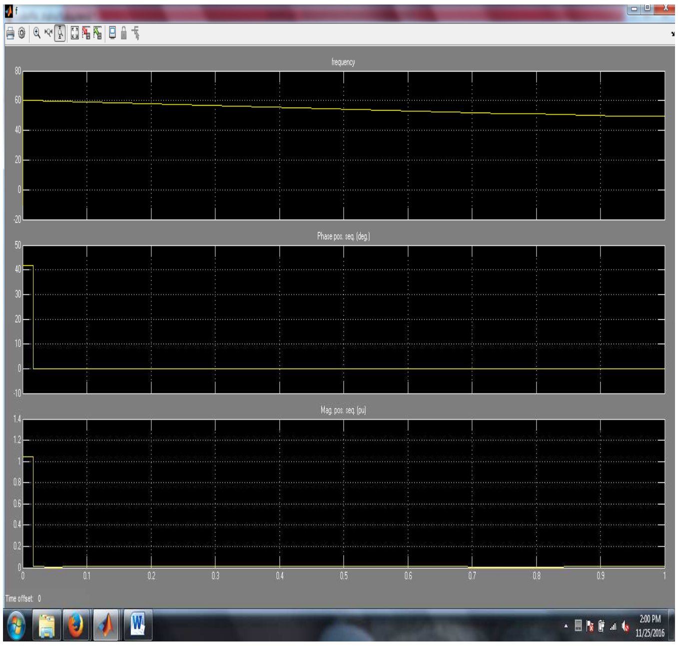
Frequency variation of the system



The frequency is determined as 49Hz through the PLL based measurement. This information is used to decide on the SCUC based generator tripping.

X Axis – time in sec
Y axis – Frequency in Hz

Before load damping at load 2

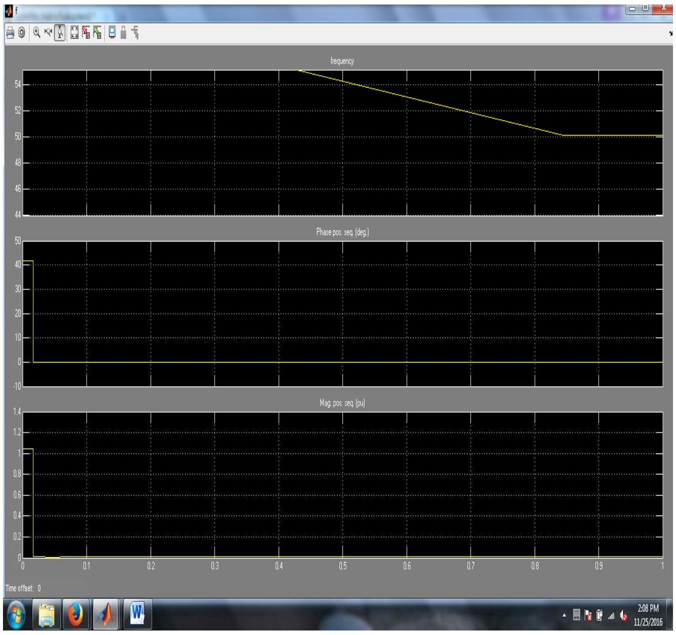


The top graph corresponds to 49.4

The figure shown above shows the measurement based on PLL and it settles to normal acceptable frequency range of less than 50.5 Hz in less than 0.8 s.

X Axis – time in sec
Y axis – Frequency in Hz

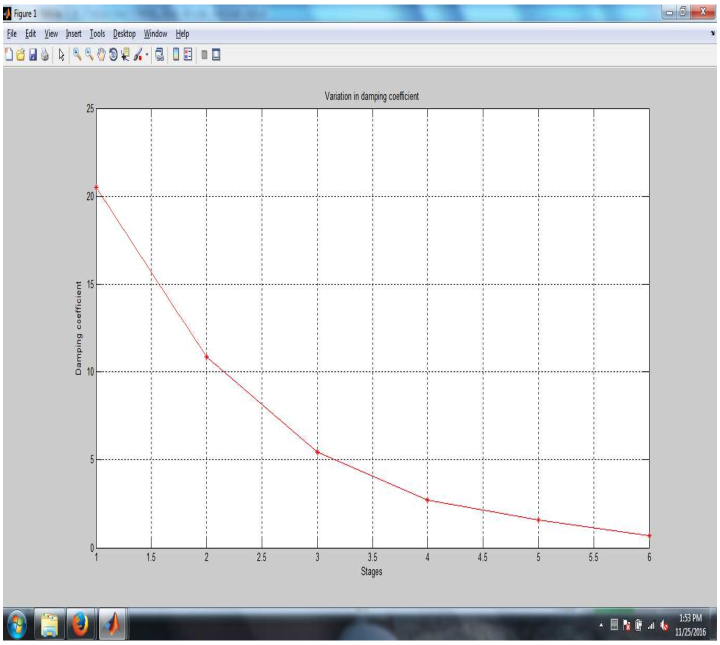
After load damping at load 2



The figure shown above shows the measurement based on PLL and it settles to normal acceptable frequency range of less than 50.5 Hz in less than 0.8 s.

X Axis – time in sec
Y axis – Frequency in Hz

Variation of damping coefficient



The diagram shows the variation of damping coefficient. This above diagram clearly reveals that the complete shed is not necessary and the loads are allowed to work but, depending on the frequency existing at that instant. In earlier cases, shedding is a drawback where loads are not allowed to consume power. But in this case, the loads are allowed to reduce its consumption slowly in an optimal way.

X Axis – Stages from 1 to 6
Y axis – Damping coefficient

V. CONCLUSION & FUTURE WORK

This project has proposed a novel load-damping characteristic control method based on the voltage characteristic of the electrolytic aluminum load. The frequency deviation is set as a feedback to control the reference voltage of the generators' excitation system when power imbalance occurs in the isolated power system due to various disturbances. The load-damping characteristic can be equivalently controlled because the gain factor of the frequency deviation can be analytically calculated and set online. The detailed calculation method is presented in this project, which is simple enough for online application. The required data for the proposed control scheme can be obtained from WAMS. Through changing the load-damping characteristics of the aluminum loads, the proposed control scheme can significantly improve the frequency regulation capability of the isolated system with small inertia. The frequency stability can be maintained in different scenarios. The proposed method is very suitable for those electrolytic industrial systems in which loads are both voltage-sensitive and interruptible in the short term, especially for the isolated power system with poor frequency regulation capacity. The basic idea of varying the load shedding values and hence the load damping coefficient is the novel idea proposed in this work. This has been verified using three different loads ranging as 10, 40 and 100W. Assuming that the generator capacity is maximum of 5A, the shedding is performed step by step simultaneously measuring the frequency. Hence, this work is a combined UFLS and power based shedding.

In this present work, neural based control schemes are used for the development of under frequency load damping problem. The fuzzy – genetic control method can also be used to design a custom membership function shape. In fuzzy – genetic controller, the genetic tuner will optimse the architecture of fuzzy model by creating the population of new process parameters. We can also use wireless technique for collecting load data, generation, rate of change of frequency in order to have fast and smooth operation of under frequency load damping.

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