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The Role of Effective Parameters in Automatic Load-Shedding Regarding Deficit of Active Power in a Power System

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ABSTRACT

Load-shedding by frequency relays is the most commonly used method for controlling the frequency of power networks within set limits and maintaining the network stability under critical conditions. In the presently used methods, when frequency drops below the operational plan's set point, the frequency relays of the system issue commands to step-wisely disconnect parts of the electrical power load, thereby preventing further frequency drop and its consequential effects.

This paper reviews various methods of frequency control and the applied methods of load-shedding for operational planning. It also deals with the advantages of using the frequency drop gradient parameter and the reasons it has not been utilized in the planning. Then the problems and solutions of using this parameter are discussed, and a new method is proposed that is based on the frequency drop gradient.

Finally, the performance of the proposed method under various conditions is compared with the methods used in a sample network, and some of its characteristics are mentioned, including speed of frequency restoration, prevention of frequency drop, and elimination of the need to decide on the number and amount of shedding steps. Despite these desirable characteristics, some effective factors that cannot be included in the simulation models inhibit a decisive judgment on the applicability and reliability of this method under real conditions. At the end of the paper, some solutions for these difficulties and the improvement of the method are proposed.

INTRODUCTION

The stability of electrical power networks has always been one of the central and fundamental issues of concern in network design and operations. Serving users of electricity is the duty of power networks that generate, transmit, and distribute electrical energy. Therefore, network growth and expansion is highly user-dependent and, the system should be able to satisfy their needs and requirements. Among the foremost and central requirements is reliability, quality of energy, and continued load-capacity. Network designers and operation managers should continuously pay due attention to these requirements and take the necessary steps to fulfill these requirements and maintain the desired qualities.

The reliability and stability of the system can also be studied from the viewpoint of the great social and economical losses that may incur in a total black-out or in partial out-of-service situations. In this context, system frequency and frequency control can be considered as a measure of user-satisfaction and stability.
Frequency is the main criteria of system quality and security because it is:

- a global variable of interconnected networks that has the same value in all parts of the network,
- an indicator of the balance between supply and demand,
- a critically important factor for the smooth operation of all users and particularly manufacturing and industries.

One of the main problems of all interconnected networks is a total black-out because of frequency drop as a consequence of some power-station failure or transmission-line breakage. Presently, in power generation and transmission systems of the world, the most appropriate way of preventing a total or partial black-out that is triggered by frequency drop is quick and automatic load-shedding.

Until 1978, the sample network's interconnected network was quite vulnerable in this respect. Then the first studies were conducted and a program of load-shedding was implemented. It is noteworthy that the latest studies of this subject date back to 1992 and the presently used plan for load-shedding is over a decade old.

All power networks of the world are presently using an automatic and step-wise load-shedding protection scheme that step-wisely activates the frequency relays specific frequency drop steps.

The main objective of this paper is a treatment of load-shedding with regard to power generation drops under severe conditions of disorder, and utilization of the frequency drop gradient parameter in planning for load-shedding.

MODELING OF THE POWER SYSTEM NETWORK FOR LOAD-SHEDDING STUDIES

In order to study situations of imbalance between power supply and demand, and the resulting frequency variations under the circumstances of sever and major disorders, a model is required.

Figure 1 shows a simplified model of the steady state for systems that consist mainly of thermal units.

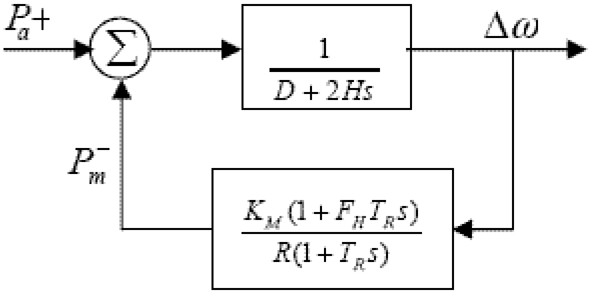

Figure 1 – Steady-State Frequency-Response Model

H = System's Inertial Constant
D = Load Damping Coefficient
K_m = Frequency Control Loop Gain
F_H = High Pressure Re-warmed Turbines' Power Portion
T_R = Re-warming Time constant
P_m = Mechanical Power of the Turbine (per unit)
T_a = Accelerator's Power
$\Delta\omega$ = Speed Change (per unit)

$$\Delta\omega = \frac{P_a}{D}(1 - e^{-\frac{D}{2H}t}) \qquad (1)$$

Equation (1) models the system at the initial conditions of major disorders when the governor's effect is lifted off all equations because during the first seconds of the disorder, due to governor's response delay and its operating time constant, it can not play a role in prevention of the frequency drop [1, 2, 3].

MAIN SYSTEM PARAMETERS AND THEIR EFFECT ON THE FREQUENCY CURVE

As the above model shows, the main factors and parameters that control the behavior of frequency vis-à-vis overloading are the amount of overloading and the D and H parameters. The effect of these two parameters should be definitely considered in load-shedding planning.

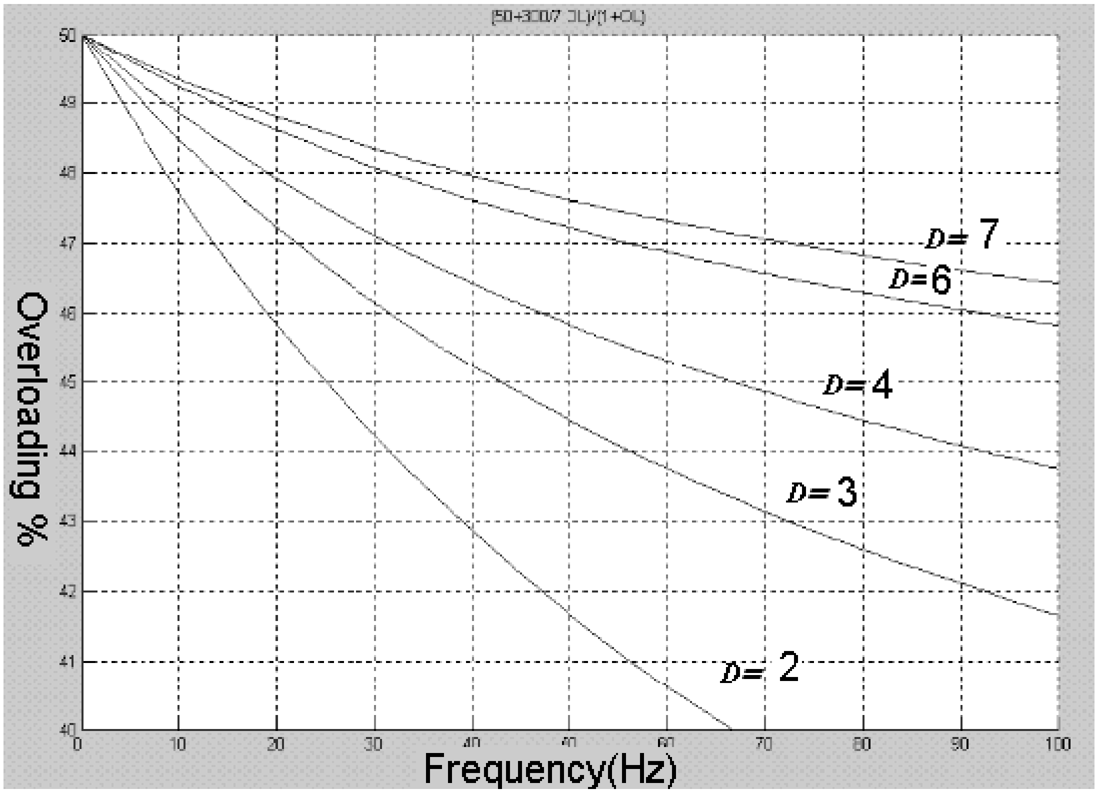

Figure 2 The effect of load damping coefficient on the frequency drop curve
(System stability curves for various overloading)

The load damping coefficient (D) is an effective parameter that represents the relation between the load and the frequency. It cannot be ignored in planning for load-shedding plans. In planning for load-shedding, the load damping coefficient is normally expressed per unit as shown in the following formula:

Equation (2) $$D = \frac{F}{P} \cdot \frac{\Delta P}{\Delta F}$$

The value of D varies from 0 to 7 and for each system is to be determined once and used in all cases of planning. The latest studies has shown D = 3.3 for the sample network [4].

The effect of D on the frequency drop gradient is quite visible as an increase in D causes a decrease in the frequency drop gradient. For any specified overloading, systems with a higher value of D will have a higher stability and the final system frequency will be stabilized at a higher level. Figure 2 clearly shows the effect of D on the frequency drop curve.

H or system's inertial constant is another factor with a considerable effect on the inertial frequency drop gradient. The interesting point about this factor that was noted during the studies related to this paper is, that unlike D, variations of H influence the initial part of the frequency drop gradient, and for a specified level of overloading, have little or no effect on the final frequency of the system. However, for regulating relays and prevention of their interference, H should be carefully considered. It should be noted that the higher the H, the better the system stability under conditions of disorder, and the system moves toward the final frequency with a less steep gradient. The value of H in various systems depends on the inertial constant of the generating units and is determined by the following formula:

$$H_{eq} = \frac{H_1.MVA_1 + H_2.MVA_2 + ...}{MVA_1 + MVA_2 + ...} \qquad (3)$$

Where H is the inertial constant of a unit and MVA is the nominal power of the unit. Figure 3 shows the effect of H variation on the frequency curve gradient [5].

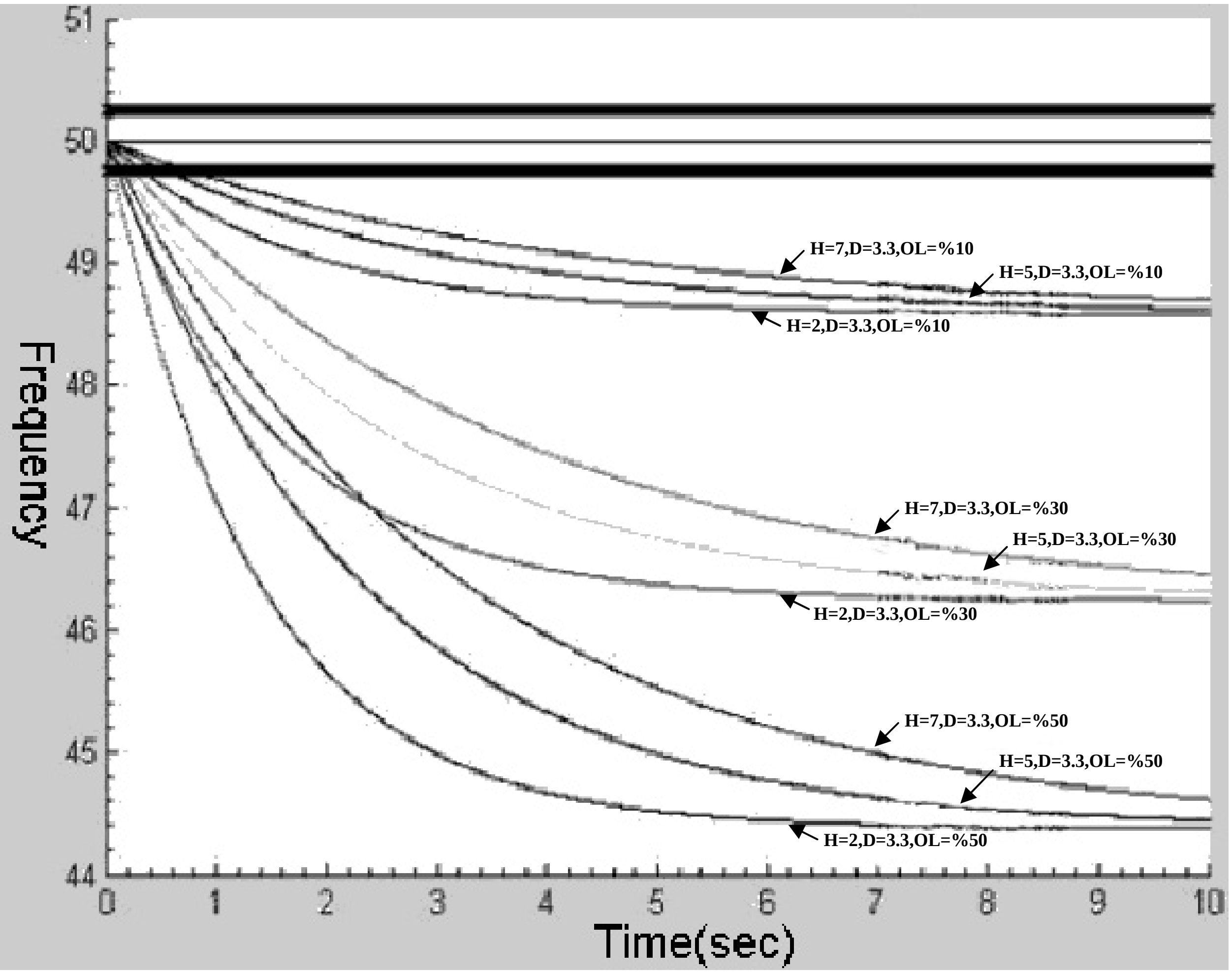

Figure 3 – Effect of Varying Inertial Constant on the gradient of frequency curve
At 10%, 30% and 50% overloads

CONVENTIONAL LOAD-SHEDDING

In commonly used step-wise methods, load-shedding planning has little relation to the degree of overload. Any overload triggers the same plan of load-shedding, as the degree of overload does not determine the number or quantity of the load-shedding.

This kind of planning greatly simplifies the task of harmonizing the relays and the steps of load-shedding, as simple calculations and a process of trial-and-error would suffice. It is one of the obvious advantages of this kind of planning. Once the steps of load-shedding are specified, if at any step the frequency continues to drop (with regards to the specified delay times), then the next step will be automatically activated until the frequency stops dropping. In such plans, increasing the number of steps can increase the costs and allow a more precise harmony and a minimized blackout area. Nevertheless, in almost all countries, only three to five steps are planned, with rare cases of more.

In such plans, the first step of load-shedding is regulated in such a way that with any frequency drop below the set point, this step is activated to operate within its specific time-delay. The time duration for frequency to drop from normal to below the set point is not taken into consideration, despite the act that we know that the gradient of frequency drop is directly proportional to the amount of overload and severity the of the case; therefore, it can be a basis to decide on whether only one step is adequate.

WHY FREQUENCY DROP GRADIENT IS NOT USED IN LOAD-SHEDDING?

One of the problems that should be noted and considered in load-shedding planning is the gradient of the frequency drop that varies with various overloads. A survey of technical literature and further research shows that despite its attractive advantages, Frequency Drop Gradient has not been used in load-shedding because of

1- The existence of natural fluctuations in frequency
2- The dependence of frequency drop gradient on variations of the parameter H, especially during the first moments.
3- The dependence of frequency drop gradient on variations of the parameter D.
4- The complexity of using this parameter in harmonizing relays and stages of load-shedding in multi-step plans.
5- Limitations in translating the detected amount of overload to instructions for frequency relays.

One of the main characteristics of the frequency drop curve is its gradient that proportionally reflects the severity of the disorder and can be used quite effectively in load-shedding plans. Frequency drop gradient and the amount of overloading are related [5, 6] as:

Equation (4)

$$R = {OL.F_n}/{2H}$$

Where R = average frequency drop gradient
OL= Overload
F_n = Nominal Frequency of the System
H = System's Inertial Constant

The above relation can be a basis for using the frequency drop gradient as a measure of overload.

A NEW APPROACH AND PROPOSALS FOR SOLVING THE REMAINING PROBLEMS

As mentioned earlier, frequency drop gradient and the amount of overload are related and directly proportional. Therefore, using H=4 (for the sample network), it is possible to estimate the overload on the basis of the average frequency drop gradient. Then, depending on the amount of overload, commands can be issued to one or more steps of relays. All additional loads can be shed in the very first step, thereby preventing further frequency drop and its consequential hazards.

Now we discuss the possible problems that may arise and their solutions.

1) Various literatures showing that the main obstacle in using this method is the existence of natural frequencies that can show a gradient much steeper than the reality and lead to over-shedding and even raising the frequency above its set point. One major problem is the difficulty of estimating the extent of fluctuations of natural frequencies. Besides, the fluctuations in different buses are different and this adding to the difficulty.
   One way to overcome this difficulty is to use the average frequency drop gradient that can be calculated by averaging the gradient in several frequency intervals. In the program developed for the purposes of this paper, this is done at the first 0.5 Hz drop, so that the shedding instruction is issued at 49.3Hz. The planners can conveniently choose other appropriate values for their desired shedding plan.
   The research uncovered some other problems that are not mentioned in the references of this paper. Following is the list of these problems and proposals for their solutions:

2) The next difficulty of using the frequency drop gradient is its dependence on system parameters that can drastically change the gradient. As mentioned earlier, the system's inertial constant influences the initial drop gradient and the coefficient of damping load can influence the final frequency drop. Various tests and evaluations indicated that the D parameter at the initial 0.5Hz drop and its changes between 2.7 and 4.2 does not significantly change the estimated gradient (the fluctuations of system inertial constant and the coefficient of load damping are based on ref [5]). Therefore, in calculations of frequency drop gradient, the load damping coefficient can be considered constantly equal to 3.3 and used in issuing the shedding inions. To compensate for the effect of H on frequency drop gradient, and noting that this is derived from the generating stations, we can use the derived value in the computations (for example, the sample network a value of

H=4 can be used). Although the changes of this parameter from 3 to 5 can influence the estimated value of the overload, it was seen that power shedding based on H=4 does prevent frequency drop quite well.

3) The third difficulty of using this method is in issuing instructions to relays for shedding the overload, because the relay already installed on any power-line controls the switch that cuts the load on the line and cannot shed part of the load on that line. One way to overcome this problem is to install several relays in the range of 3% to 10% on the line and issue instructions to a combination of these relays; thereby, shedding 3% to 50% of the load can be disconnected quite conveniently. Alternatively, the currently used relays of the sample network may be used that allow load-shedding in the ranges 6.7%, 7.4%, 9.4%, 14.1%, 15.4%, 16.1%, 16.8%, 18.1%, 22.8%, 23.5%, 24%., 25.5%, and 32.2%. Using the existing relays is more economical than procuring new relays although it does not cover more than 25% of the load. Other or better ways may also be found to solve this problem but they may require further investment and research. So in this paper we have reached to the second method that uses the existing relays of the sample network.
   The other difficulty in implementing this plan is the mode of issuing instructions to the relay. Following is a set of solutions for this problem:

   (A)- Using a central command and control system equipped with intelligent, high-speed, and programmable equipments that are capable of real-time data acquisition and monitoring, and that at critical times of disorder can quickly perform the calculation of overload, decide on the relays that need to be activated and issue the necessary load-shedding commands to those relays. The high level of reliability is a solid requirement, and the probabilities of delay in issuing commands or timely operation of the relays argue against adaptation of this system.

   (B)- Using a local monitoring, command and control system, by installing an intelligent programmable system for each relay that will determine the amount of overload, and issue the necessary command to the relay. This system will cost more but provides a higher reliability.

4) The next major problem is the complexities involved in harmonizing the load-shedding steps, and several references have counted this problem as the main obstacle in using the frequency drop gradient for load-shedding plans. However, this problem can be simply solved by a single-step plan that determines the amount of overload in the very first step and performs the required load-shedding.

COMPARISON OF RESULTS

The following method, as proposed in this paper is a new approach and will be compared with the currently implemented method in the sample network:

In this method, the amount of overload is estimated on the basis of average frequency drop gradient as obtained from the initial 0.5Hz drop that closely approximates the actual operation of the system. The value of H parameter is assumed to be equal to 4 (for the sample network).

First for various overloads of 10%, 12%, 15%, 18% 20%, 23%, 25%, 28%, 30% and 35%, and H=4, and D=3.3, the results were compared with the currently used method in the sample network. The results for OL=15% and OL=28% are shown in figure (4) and figure (5).

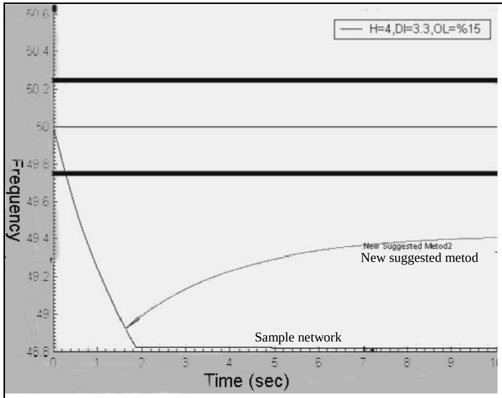	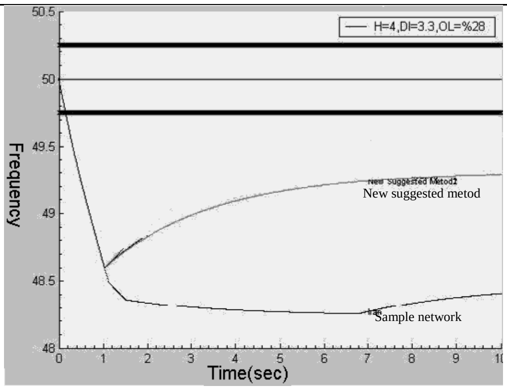
Figure 4- Load shedding @ 15% overload	Figure 5- Load shedding @ 28% overload

Both results show a distinct superiority of the proposed method over the currently used method in the sample network, from the viewpoints of frequency restoration speed and the shape of restoration curve. The results obtained in the above tests can be improved in a complete plan of load-shedding.

To investigate the effects of H parameter variations on the proposed method and the conventional method, some comparisons were made as shown in figures (6), (7), (8), and (9). These curves indicate that although any positive or negative change in H influences the frequency drop gradient and the estimated overload, nevertheless, the proposed method yield better results than the conventional method and has a better frequency-response curve after the load-shedding.

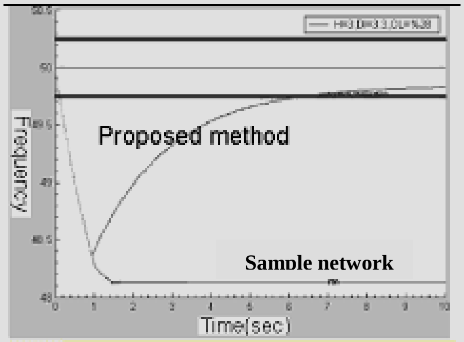

Figure (6) - D=3.3, H=3, OL=28%

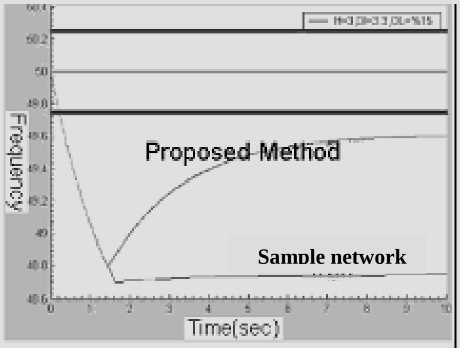

Figure 7- D=3.3, H = 3, OL=15%

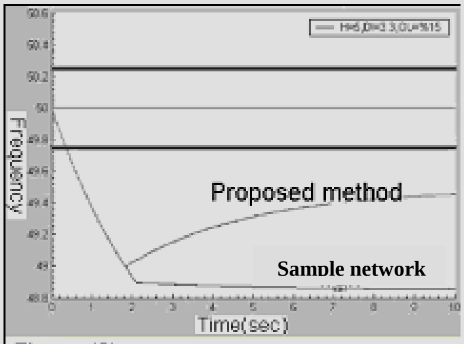

Figure (8) - D=3.3, H=5, OL=15%

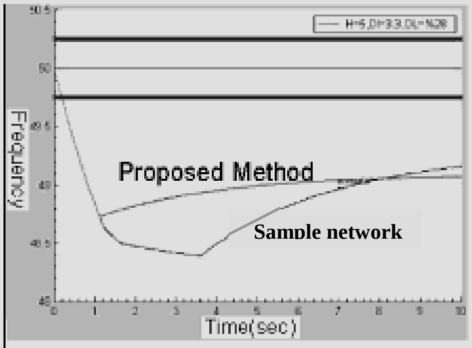

Figure 9- D=3.3, H = 5, OL=28%

Figure 6, 7, 8 and 9 H parameter variations on the proposed method and the conventional method

It is noteworthy that at H=5 for overloads greater than 25%, the frequency-response curve of the conventional method surpasses the curve of proposed method and is stabilized at a higher frequency (Figure 9). This is due to the load-shedding limitations of the relays in the sample network and variations in the system's inertial constant, as both of these affect the estimation of overload. Considering the fact that just a few seconds after the frequency drop and its prevention via additional generation (automatic load control) or utilizing the rotating reserves, the frequency is restored to its normal level, this effect can be ignored. Besides, the proposed method works faster in the prevention of drop and restoration of frequency and these are the main advantageous characteristics of the proposed method. Note that that the operating point and load shedding point are lower because of the time delay of the relays. Since the relays' time delay is assumed to be constant, then the operating point for higher OL will be below the operating point of lower OL.

The above figures indicate that reduced inertial constant results in over-estimation of the OL, and the power-load that will be shed would be higher than what is needed, driving the curve towards the 50Hz more within the permissible set points. On the other hand, an increase in the inertial constant creates a reverse effect, and as can be seen in the figures, the frequency restoration curve will be below the normal position and even the conventional method's curve. However, the plan is designed in a way that it can respond appropriately in such disorderly situations.

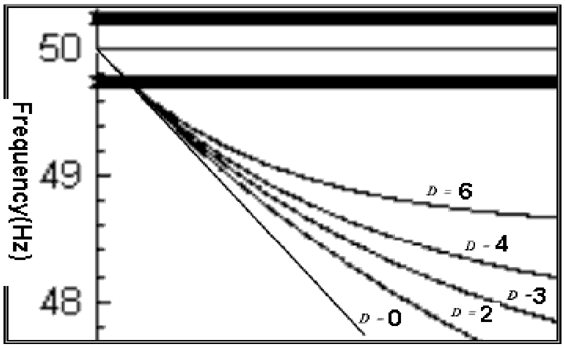

Figure 10 - Effects of load damping coefficient on the frequency drop gradient at initial moments

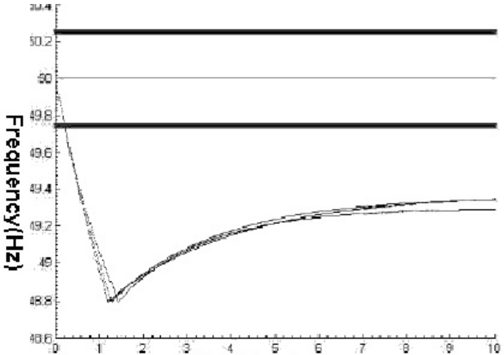

Figure 11- Effects of Load Damping Coefficient for H=4 and D=4.23, 3.3, 2.7

Reference variations of the parameter D, as was mentioned earlier and is apparent from the Figure (10) has no significant effect on the estimation of the OL within the initial 0.5 Hz range and can be ignored.

To show the insignificance of the D variations, load-shedding for various values of D between 2.7 and 4.2 are shown in Figure 11. This clearly shows that its variations do not cause any disorders and can be ignored although its effects can be precisely considered in the plan.

CONCLUSION

This paper has attempted to take a step forward in improvement of the sample network's power network performance. New efforts towards the preset objectives will be based on the results obtained so far, as outlined below:

As the studies and comparisons of results indicate, the proposed method can yield better results than the conventional step-wise method, although these conclusions are based on necessary but insufficient simulation approaches and time-frequency relationships. The model needs to be refined by incorporation of system parameters and natural frequencies under actual conditions. Such parameters are not predictable in this simulation effort. Either real and actual values or generally acceptable values should be fed to this system. In short, the plan is successful within the bounds and limitations of a simulation, but its final approval depends on its examination in real environment.

FUTURE SUGGESTIONS

1- This project showed the feasibility of a plan based on the frequency drop gradient and estimation of the overload. Therefore, it seems advisable to conduct further studies including a combination of the proposed method and the step-wise method, enhancement of this plan to a multi-stage plan, island approach, etc.

2- Investigation of the effectiveness of the proposed method in actual conditions and real environments. The obtained results may be compared with the simulation studies for adoption of the best method.
3- Replacement of the electromechanical relays by static and digital relays, as the modern relays offer more and better functionalities and have a higher precision.
4- Investment for revising the current systems in the sample network, with a thorough analysis of all new plans including the one specified in this paper to establish an optimized method for load-shedding.

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