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Improvement using frequency relays compared to dynamic and static relays in frequency instability

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Abstract

Nowadays a smarter, more diverse and robust electricity infrastructure is necessary because power grids form one of the most effective components of the infrastructure on which modern society depends on. The stability of an electrical grid is very important for suppliers and consumers. Frequency variations cause instability in the electricity grid. There will be so many problems such as overproduction, overloading, and etc. which have irreversible effects on suppliers and consumers. Balancing the isolated systems in terms of production and consumption, and also using the frequency relays in power grids are useful ways to solve these problems. Due to the importance of frequency relays in proportion than dynamic and static relays, designing and optimizing the frequency relays are very important to guarantee the stability of the electrical grid. The frequency relays can be used in a different network with different charges. The frequency relays have two parts, namely measurement, and detection which undertake separate tasks. In this paper, we investigated the function of frequency relays. We also simulated and analyzed the aforementioned issues. The simulation provides a comparison of grid charge variations and nominal frequency in a state of disarray and approach to the ideal state. Some blocks have been used for counting the frequency in this simulation which most notably, included a block of frequency measurement and another block that has the protection duty.

Keywords: Frequency relays; Grid frequency and network stability

Introduction

Energy transmission networks, generators, transformers and power equipment have encountered failures due to the lack of insulation, or weakened electric, dynamics, and mechanics strength against unforeseen voltages shock, and also extreme increasing in temperature whereby cause to an electrical power outage. These electrical failures will appear due to short circuit, grounding system, tearing and cutting of conductors, and breaking insulating materials and etc. Parts and instruments with such errors must be separated immediately from the network. Energy transmission network must be designed with stability and sustainability. If we have a customer with outage power in the industrial section, we should provide it again as soon as possible because it can raise irreparable losses. When failures occur in some part of the network, those parts should be separate immediately to prevent the proliferation and spread error. The network designing should be stable. Searching, finding, and evaluating the errors are relays task. If the error is dangerous, the out of order device should be removed. This type of protection called selective protection or local protection. The selective protection is not only depended on the correct choice of protective device but it also relies on the distribution and transmission system. The selective protection can be created only in networks with two generators or in the ring networks. Whatever the network is broader and with more details, more protection devices have been required. For example, when a connection has been created the protective devices should be adjusted. This is the coordination of protective equipment that prevents untimely discontinuation in some parts of the network. So, if the protective system design and implementation are quite correct then it must operate in the nearest key to the junction; and only the defective part should be removed from the network. The number and type of protective devices and relays are depended on the importance of network equipment devices. For example, a generator in one power plant needs more protection device than a consumer device and a water pump. Meanwhile, Power failures are particularly critical at sites where the environment and public safety are at risk. Institutions such as hospitals, sewage treatment plants, mines, shelters and etc. will usually have backup power sources such as standby generators, which will automatically start up when electrical power is lost. Other critical systems, such as telecommunication, are also required to have emergency power. The battery room of a telephone exchange usually has arrays of lead–Acid batteries for backup and also a socket for connecting a generator during extended periods of outage. The Relays should have high sensitivity and

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accuracy to ensure network uninterrupted work and preserving the grid stability (Aman *et al*., 2012).

(Power) Line frequency

The constant frequency power system is one of the most important parameters. Several factors influence the choice of frequency in an AC system. Lighting, motors, transformers, generators and transmission lines all have characteristics which depend on the power frequency. All of these factors interact and make a selection of a power frequency a matter of considerable importance. The best frequency is a compromise between contradictory requirements. Most AC motors work with speeds which the optimal performance is related to a frequency. High drop frequency may lead to creating strong flows of magnetic in the induction motors and transformers and causes irreparable damages. Also, generators turbines, especially steam turbines have been designed to work in a very precise speed. If the error frequency is kept constant in a certain range, then the overall performances can be managed better. Today, Electric clocksare very common. An electric clock is a clock that is powered by electricity, as opposed to a mechanical clock which is powered by a hanging weight or a mainspring. In the 1930s the synchronous electric clock replaced mechanical clocks as the most widely used type of clock. The Accuracy of this type of clocks is the integral function of the frequency error. The AC motors cannot determine the correct frequency limits. A vast majority of electric charges that can be rotated with AC motors probably are not sensitive to the change of frequency to 2 Hz rate. The constancy of the speed of the turbine is very crucial. The frequency is a sensitive indicator of energy balance in the system, therefore should be used as an input signal to control the power system. In fact, the electric charge frequency control is one of the basic controls in a power system that automatically occurs in all power plants (Delfino *et al*., 2001).

Remove the electric charge on the power system: Removing the electric charge in a power system is useful to prevent a decrease in the frequency and generally are expected to transfer from a critical and emergency condition to an acceptable and sustainable condition. Removing electric charges in one sentence is a scheme which there the frequency is less than the nominal frequency, and power system stability is maintained by removing some of the electric charges(Lakra and Kirar, 2001). Electric charge removing is done automatically with the frequency relays and due it is the last solution to maintain system stability, care must be taken in all the calculations, to returns the system to normal with minimal electric charge removing in a short time. In the network power to remove theelectric charge, we should cut electric charge in the low voltage because if the existing electric charge has been removed in the high voltage, a switching condition will be imposed on the system and there is a possibility of power system transient instability. Equipment and the smaller division of the system become independent and already are predicted. Frequency control devices must be available to separate small systems can be connected to the grid.

Frequency relay function

Electric power generation and a reliable and economical interconnected system arethe main aims of the power system control, and also voltages and frequency must take place within exposure limits. The output power of a generator controlled with by varying mechanical power input. The flow of input steam or hot water to steam turbines or water turbines must be set with opening or closing the valve. It causes to control the mechanical strength and the power output of the generator. If the power consumption increases, the valve must open more to equally increase the power generator production. The valves must be open in certain specific to reduce power consumption. The imbalance of power can be felt of its impact on speed or frequency of generator because generators tend to increase its speed and frequency in case of electric charge reduction or excess production. In the case of overloading and production shortages, speed and frequency of generator will decline. Grid frequency deviation is selected as a signal to stimulate the automatic control system because the active power balance has been considered as constant frequency. Frequency stability is obligatory in order to satisfactory performance in a power system because it follows the relatively accurate frequency control speed stability of synchronous and induction motors. The constant speed in motor electric charges is very important especially for satisfactory performance in manufacturing plants. These units are heavily dependent on the performance of all peripheral stimuli related to fuel, water, and the combustion air feeding systems. Due to this fact that the required power of a large power system has been supplied by a large number of generators, the demanded power changes should be divided between units. The electric charge distribution between the generator and the primary control of speed carried out with installed governors on the generator, but we need a complementary control for fine tuning frequency at a nominal value which should be done in the main control center (Wichert and Dhaliwal, 1978). Mechanical power generated by the turbine is converted into electrical energy by the generator. The mechanical torque in turbines has been created through the force of water or steam or combustion gasses, and the electric torque is the result of electric charges connection which the difference between the two torque caused by fluctuations in the speed of generator (Jung *et al*., 2002).

Controller design

Since the system parameters are not known precisely, so we use the following model which also contains uncertainty:

$$\dot{x}(t) = (\bar{A} + \Delta A)\, x(t) + (\bar{B} + \Delta B)\, u(t) \text{ ....(1)}$$

$\bar{A}$ and $\bar{B}$ are nominal constant matrices. It is obvious from the model structure that the ΔA matrix is uncertainty from prime dimension; which means:

$$\Delta A = \sum_{i=1}^{3} A_i r_i(t) \text{ ....(2)}$$

A_i's are constant matrices, $\Delta B = \alpha(t)\bar{B}$, $|r_i(t)| \le \bar{r}$, and $|\alpha(t)| \le \alpha$. We are going to design controlling linear feedback $u(t) = -Kx(t)$ so that the overall closed-loop system is asymptotically stable for all the acceptable uncertainties (Kazovsky, 1982). Since the degree of uncertainty is 1, the Ai's are as follow:

$$A_i = d_i\, e_i^T \text{ ....(3)}$$

Which d_i and e_i (i=1, 2, 3) are constant vectors.

We shall consider the following Riccati equation for the design of a resistant charge-frequency controller (Kundur, 1994):

$$P\bar{A} + \bar{A}^T P - P\{\frac{2}{\varepsilon}(1-\alpha)\bar{B}R_\varepsilon^{-1}\bar{B}^T - \frac{1}{\varepsilon_1}T\}P + \varepsilon_1 U + \varepsilon Q = 0 \text{ ....(4)}$$

1. The effects of changes in frequency of the power grid stability

Mechanical power generated by the turbine is converted into electrical energy by the generator. The mechanical torque in turbines has been created through the force of water or steam or combustion gasses, and the electric torque is the result of electric charges connection which the difference between the two torque caused by fluctuations in the speed of the generator. Here a frequency relay has been designed and simulated according to the prior formula and block diagrams. Now, to prove our statements, we add the main part of the frequency relay. "Figure 1" indicated the location of the frequency relay along with other components.

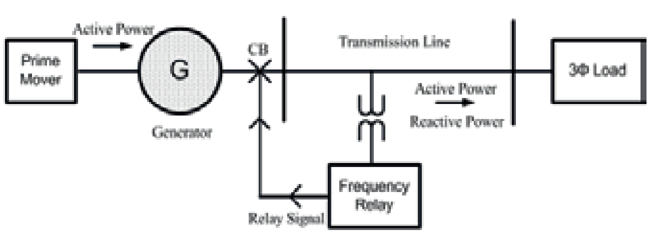

Fig. 1. The location of the frequency relay

Materials and methods

Simulation of frequency relays

In this paper, a network study method is proposed. Here, due to various factors and the complexity of the power network stability, we simulated the frequency relay by the MATLAB software. We can design and analysis of power network by using this software in different situations. Frequency relay simulation and performance evaluation are a quantitative technique which mainly has been used to study and assess the various options. This is possible through the real network modeling and execution of tests on the model. This paper indicated the design process and various data frequency relays, and also its important role in the stability of the power network. Designed and simulated relay covers both high and low frequency. These frequency relays in proportion to static and dynamic relays have higher speed and accuracy. Big changes in frequency can lead to the unstable grid and network outage. According to the history of the blackout, several nationwide power outages occurred due to frequency instability. The stability of the power grid is one of the main problems in power systems. Therefore, reconstruction of power and integration of distributed power generated by the power network, stability, synchronization, and protection are very important. The simulation tools allow the researchers to see the system in abnormal conditions and predict strategies to prevent network instability.

Results and discussion

The discharging at the first part of the simulation, the electric charge has been eliminated from the power network in two steps. First, 40 MW is separated from the network by 70 seconds. And again 70 MW is separated from the network at 120 seconds. "Figure 2" illustrated both, the production and removal status of generators.

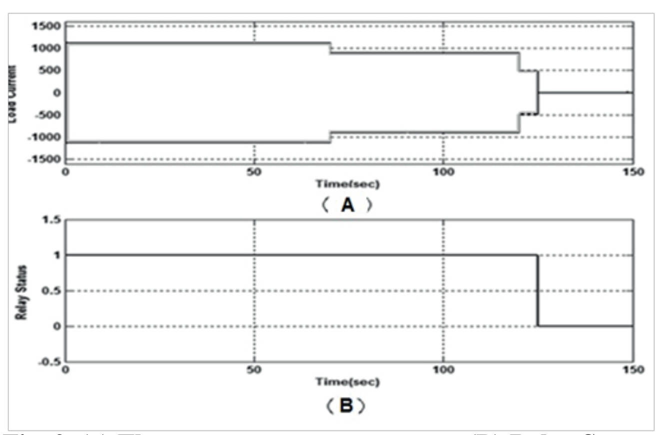

Fig. 2. (a) The generator output current, (B) Relay Status

In this condition, for the first elimination at 70 seconds, no trip command is issued by the frequency relay, and the generator production is reduced until the network frequency reaches to the nominal frequency of network, and in addition to remaining parallel with the grid, grid stability is preserved. But when a larger charge at 120 seconds has been separated from the network, eventually, the frequency relay trip command has been issued on the generator breaker and separates the generator from the network and put it in charge-less condition with the nominal round. "Figure 3" indicated the changes in grid frequency.

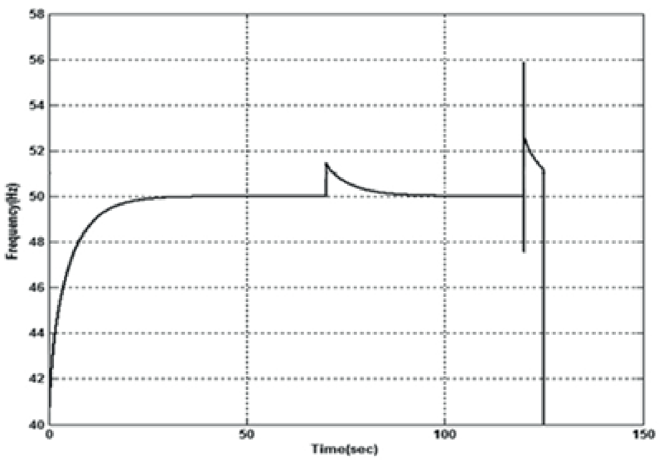

Fig. 3. The changes in grid frequency

Adding charge to the network

In this section, unlike in prior charges are added to the network. In this case, initially at 70 seconds 40 MW will be added to the network charges and the network charges achieves to 150 MW and again at 120 seconds,50 MW will be added to the network charges. "Figure 4" indicated the output current of the generator and the status of the relay when the charge is added.

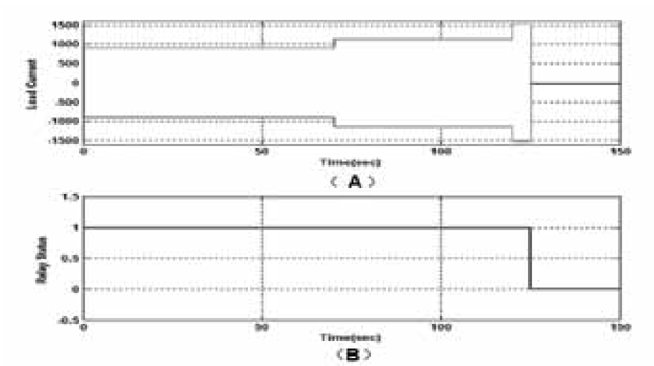

Fig. 4. (a) The output current of generator (B). The status of the relay when charge is added

According to the following curve, at the first step, the grid frequency decreases. However, with increased production, and equal production and consumption in generators, the grid frequency takes place in its nominal position. Since the time of these conditions is in total less than 5 seconds, the trip command is not issued to the generator breaker. The generators remain in the network and network stability is preserved in this case. In the second step which again we add 50 MW to the network charge, frequency decreases. In this condition, the grid frequency decreases from the defined limit, the frequency relays is declined, and also time to stay in this situation is over than 5 seconds. The trip command from the relay is issued to the generator breaker and separates the generator from the network and puts it in charge-less status.

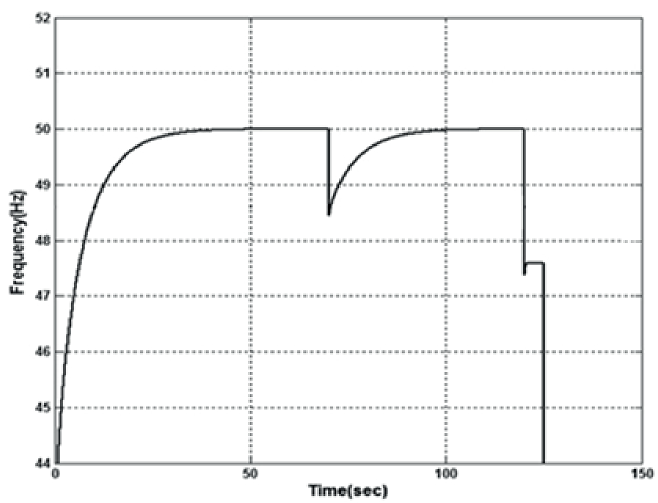

Fig. 5. The grid frequency curve while adding charges

Transient conditions

In the second situation under transient conditions, we examine the behavior of the frequency relay. In this situation, in a moment, one of the electric charges separated from the network. Again with error handling in place, the breaker is closed again and the charge takes place on the network. Disconnect and reconnect occurs in less than 5 seconds. In this situation, with cutting the breaker the charge decreases to 80 MW in 70th seconds. In the 75th second, 80 MW comes back to the network again. "Figure 6" indicated the output current of the generator and the status of the relay under temporary error.

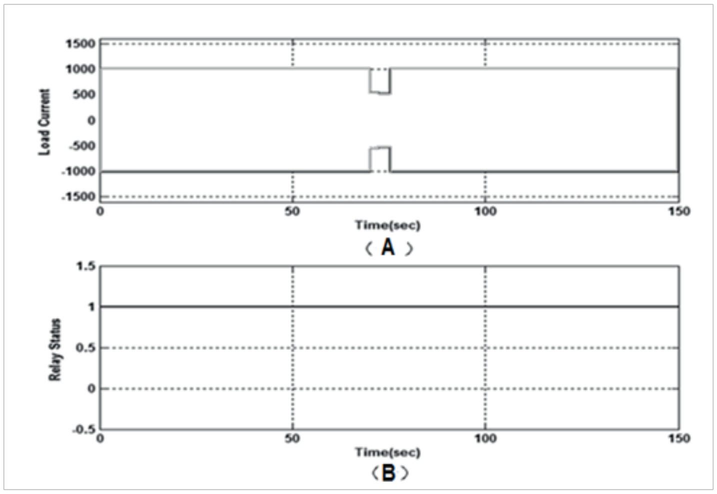

Fig. 6. (a) The generator output current, (b) The status of the relay

As already has been shown, there is an integrator in the block diagram of the relay which determines the limit of grid frequency when the grid frequency is higher or lower than the defined value. And when the time goes over than 5 seconds, the breaker trip command is issued to the generator. "Figure 7" illustrates the performance of the block diagram.

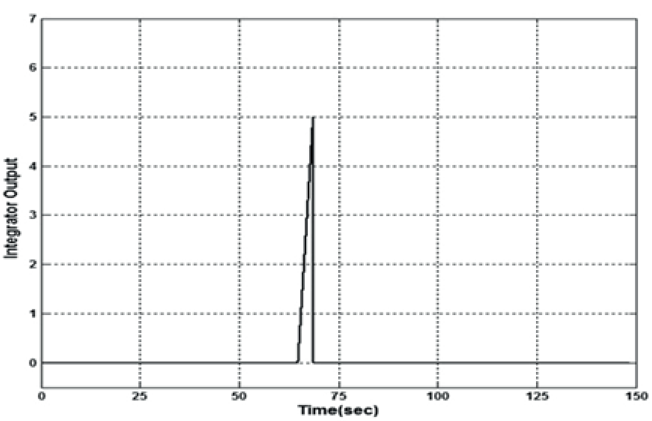

Fig. 7. The frequency changes diagram

The frequency relay function when adding and cutting an electric charge

In this situation, we investigated the frequency relay behavior in other situations. First, at 70th second, we add 80 MW to the base of the grid which already is 150 MW. Then at the 74th second, we separate 80 MW from the grid. In this situation, when the charge has been added to the network, grid frequency decreases in accordance with the charge, and at the same time, generator production increases. As long as the grid frequency is equal to the nominal frequency, generator production decreases in order to normalize the frequency of the grid. At the 120th second, the 80 MW will add to the grid, and the reaction of generator and frequency relay is same as before. After 5 seconds, the breaker trip command is issued to the generator and then separates the generator from the grid by opening the breaker.

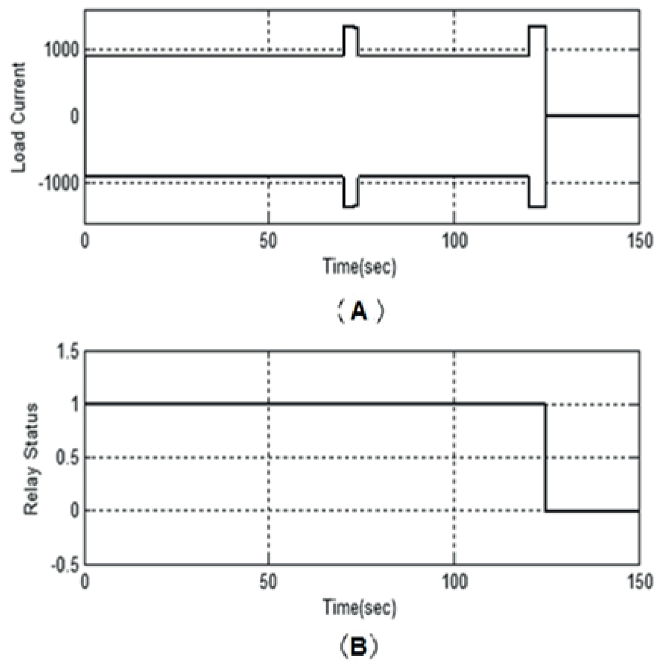

Fig. 8. (a) The generator output current, (b) Relay status

"Figure 9" illustrated the integrator of frequency relays from 70th to 74th second, which its time is not 5 seconds, and the relay output does not open the breaker of the generator. But in the 120th second the output of integrator takes long more than 5 seconds. The output of relay is issued to the breaker of the generator and separates the generator from the grid.

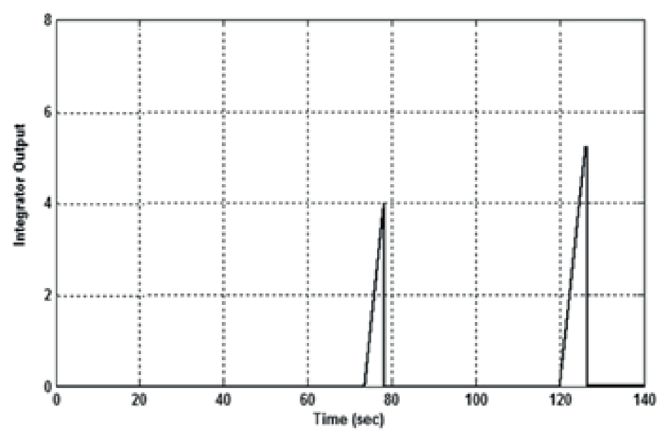

Fig. 9. Frequency variations

Conclusion

Establishing a balance between suppliers and consumer is one of the most important things for a stable and reliable network because under these conditions the system frequency can be kept in a standard range and provide the security and quality of generated electricity. Since it is impossible to save electricity in the high consumption, and also it is not affordable, so there is always the possibility of imbalance between production and consumption and eventually the system frequency deviation from the nominal value due to the uncertainty of the anticipated charges. The frequency deviation from the nominal value will cause instability in the network. As if the production is greater than consumption, the network frequency will increase; and if the production is less than consumption, the network frequency will decrease. The imbalance between supplier and consumer can be determined by its impact on the speed and the frequency of thegenerator. After reviewing the past works which include types of protection, relays performance and etc. we studied the function of relays. We investigated the various network charges and their behavior in various conditions, the inertia constant, the frequency response of the governor, the damping coefficients and power turbine, etc. to increase the speed and accuracy in frequency relays. The frequency relays can be used in a different network with different charges. The frequency relays have two parts, namely measurement, and detection which undertake separate tasks. The frequency of power system reduces or increases, due to the adding or removing charges to the grid. The generator compensates the frequency decrease and this situation continuous until the frequency gets out of the range. When the frequency reaches the defined time limit, the open command is issued by the relay. The recommendations are offered as follows:

According to the development of energy resources and getting more consumers and the need for greater stability, it is recommended to investigate the system stability in terms of other parameters.

Providing new algorithms to eliminate the network load, and also in order to increase the stability for frequency deviation.

Using new approach for affecting different charges in power networks due to frequency and voltage drop.

Using frequency relays in other parts of the power network.

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