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Modelling and Simulation of Digital Frequency Relay for Generator Protection

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ABSTRACT

Stability of system is one of the major issues of power system. Voltage, angle and frequency instability are the basic instability problems. After power system restructuring and the incorporation of distributed generation in power system, stability and protection coordination issues have become a centre of concern for power researchers. Frequency instability is the deviation of the frequency from its nominal value. Load shedding is the principle reason for frequency deviations in power system network. The large frequency variations could lead to complete power system blackout. History has seen several blackouts due to frequency instability, either due to supply-demand unbalance or N-1 contingency. Frequency relays are employed to detect and protect the system from frequency deviations. With distributed generators penetrating into the system and possible islanding issues, frequency relay has again gain the attention of the researchers and industrialists. The digital relay has superiority over electromechanical relay in terms of accuracy and speed. This dissertation presents the design and various data conversion steps of a digital frequency relay. The designed relay will cover both over and under frequency conditions. To validate the performance of proposed and studied digital frequency relay, extensive simulations under various conditions of steady state, transient , under frequency and upper frequency, are carried out in MATLAB/ Simulink environment.

KEYWORDS: Frequency Relay, Swing Equation, Relay Modeling.

I. INTRODUCTION

Stability of system is one of the major issues of power system. Voltage, Angle and Frequency instability are the basic instability problems. After power system restructuring and the incorporation of distributed generation in power system, stability and protection coordination issues have become a centre of concern for power researchers. Modelling tools are utilized to simulate the system and see the possible impacts during abnormalities. MATLAB, most widely used educational and research software, is also among these tools. However, currently MATLAB power system library has no tool box for power system protection. In this thesis, a digital frequency block is designed. The design block offers flexibility in terms of further research and improvement. Frequency instability problem arises when there is a large mismatch between demand and supply or due to N -1 contingency.

Mechanical power is produced from turbine and transferred to the generator shaft. A generator converts the mechanical power into the electrical power P_e. Mechanical Torque T_m is created on the turbine from the water or steam power and electrical torque T_e is as a result of load connection. The difference between the two torques(known as acceleration torque), causes the fluctuation on the generators speed, and thus resulting in speed variation of the frequency of the power system.

Swing Equation:

The swing Eqn. (1) demonstrates the relationship between the deviation of the torque and variation of angular acceleration (5)

$$J\frac{d\omega}{dt} = T_m - T_e \qquad (1)$$

$$J\omega_m\frac{d\omega}{dt} = P_m - P_e \qquad (2)$$

Where J is the total moment of inertia of the rotor mass, ω_m is the angular mechanical velocity, P_m and P_e are the mechanical and electrical power , given by Eqn. (3)

$$P_m = \omega_m T_m; \qquad P_e = \omega_m T_e \tag{3}$$

A normalized inertia constant (H)is defined as :

$$H = \frac{Stored\ kinetic\ energyat\ syns.speed\ (MJ)}{Generator\ MVA\ rating} \tag{4}$$

$$H = \frac{J\omega_s^2}{2S_{rated}} \tag{5}$$

If P is the number of poles in synchronous machine then the mechanical speed (ω_m) is related to the electrical speed (ω) by Eqn. (6)

$$\omega = \frac{P}{2} * \omega_m \tag{6}$$

Substituting Eqn. (5) and (6) into Eqn. (2) results in

$$\frac{2H}{\omega_s} * S_{rated} * \frac{d\omega}{dt} = P_m - P_e \tag{7}$$

Dividing the Eqn. (7) by S_{base}

$$\frac{2H}{\omega_s} * \frac{S_{rated}}{S_{base}} * \frac{d\omega}{dt} = \frac{P_m}{S_{base}} - \frac{P_e}{S_{base}} \tag{8}$$

Now, the Eqn. (8) can appear in per unit

$$\frac{2H}{\omega_s} * \frac{d\omega}{dt} = P_{m(pu)} - P_{e(pu)} \tag{9}$$

Where P_e (pu) and P_m (pu) are the per unit electrical power and mechanical power. From Eqn. (9), the relation between change in frequency and power could be developed, given by Eqn. (10).

$$\frac{df}{dt} = \frac{f_n}{2H} * \Delta P \tag{10}$$

Where f_n is the system frequency or rated frequency. From Eqn. (10), it can be observed that the mismatches between demand and supply results in frequency change.

II. DIGITAL FREQUENCY RELAY

Digital frequency relay (DFR) is a powerful computing and mathematical tool which have been used independently in applied signal processing and more importantly in the area of power protection analysis.

A basic difficulty with using and producing electric energy is that apart from short periods of time and small quantities electric energy cannot be stored. It must be produced at the same time as it is used. To maintain the balance between power production and consumption, the power plants that produce the energy must be continuously regulated. Power system control is based on the phenomenon that in case of an imbalance, the AC frequency of the network changes.

During normal operation of the electric grid, the system frequency kept near a set value, but it is allowed to fluctuate within certain bound.

OVER-UNDER FREQUENCY RELAY

Frequency relay is commonly used in order to protect the power system from blackout in case of major generation/load loss or during N-1 contingency. The relay is also used to detect the islanding operation. Islanding operation normally occurs in case of distributed generation due to loss of mains. The resulting system consisting of distributed generator and local load is often known as "Power Island". This presents a threat to the system in terms of power balancing and controlling. A major threat comes when the power island is reconnected to the rest of the system without synchronising first. Loss of mains is often detected by measuring rate of change of frequency (ROCOF). However ROCOF method cannot reliably discriminate between changes in frequency due to loss of mains and changes due to other disturbances. In this, the author has also proposed the comparison of rate of change of frequency (COROCOF) for loss of main protection. Stable frequency operation is always demand of customer. Different countries have their own grid codes to ensure that the quality (voltage and frequency) of electricity supply is maintained within specified standards. For example, in UK following the Electricity Supply Regulations 1989 and the Grid Code the frequency delivered to the consumer must not vary more than ±1%. Also ±6% variation in voltages is allowed below 132 kV whereas ±10% regulation is allowed for voltages higher than 132 kV.

III.MODELING AND SIMULATION OF DFR

The Digital Frequency Relay consists of two parts, Frequency Measuring Unit (FMU) and Under-Over Frequency Detection Element (FDE), as shown in Fig. 1 . FMU is used to measure the digital value of frequency from the PT while FDE takes appropriate action based on Over Under frequency limit.

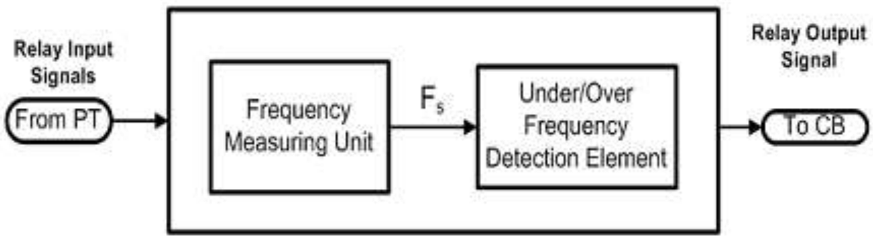


Fig. 1: Block Diagram for Implementing Over-Under Frequency Relay.

A. FREQUENCY MEASURING UNIT

The FMU is used to measure the frequency of a voltage signal from the Potential Transformer (PT). To measure the frequency, the time difference between the two consecutive zero crossing (T1 and T2) is measured, as shown in Fig.2`

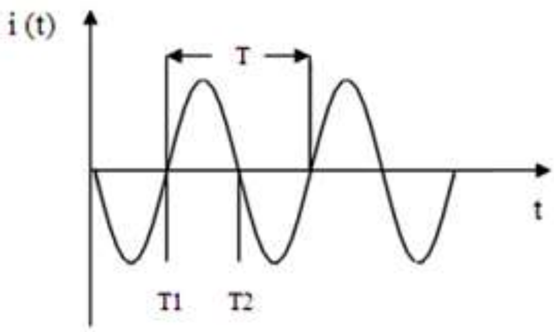


Fig .2: Measuring Frequency of a Signal.

However to measure the total time of a complete waveform, the difference between T1 and T2 is multiplied by factor of 2, as shown in Eq. (11)

$$T = 2 * (T_2 - T_1) \quad (11)$$

The FMU unit implemented on SIMULINK in Fig. 3.

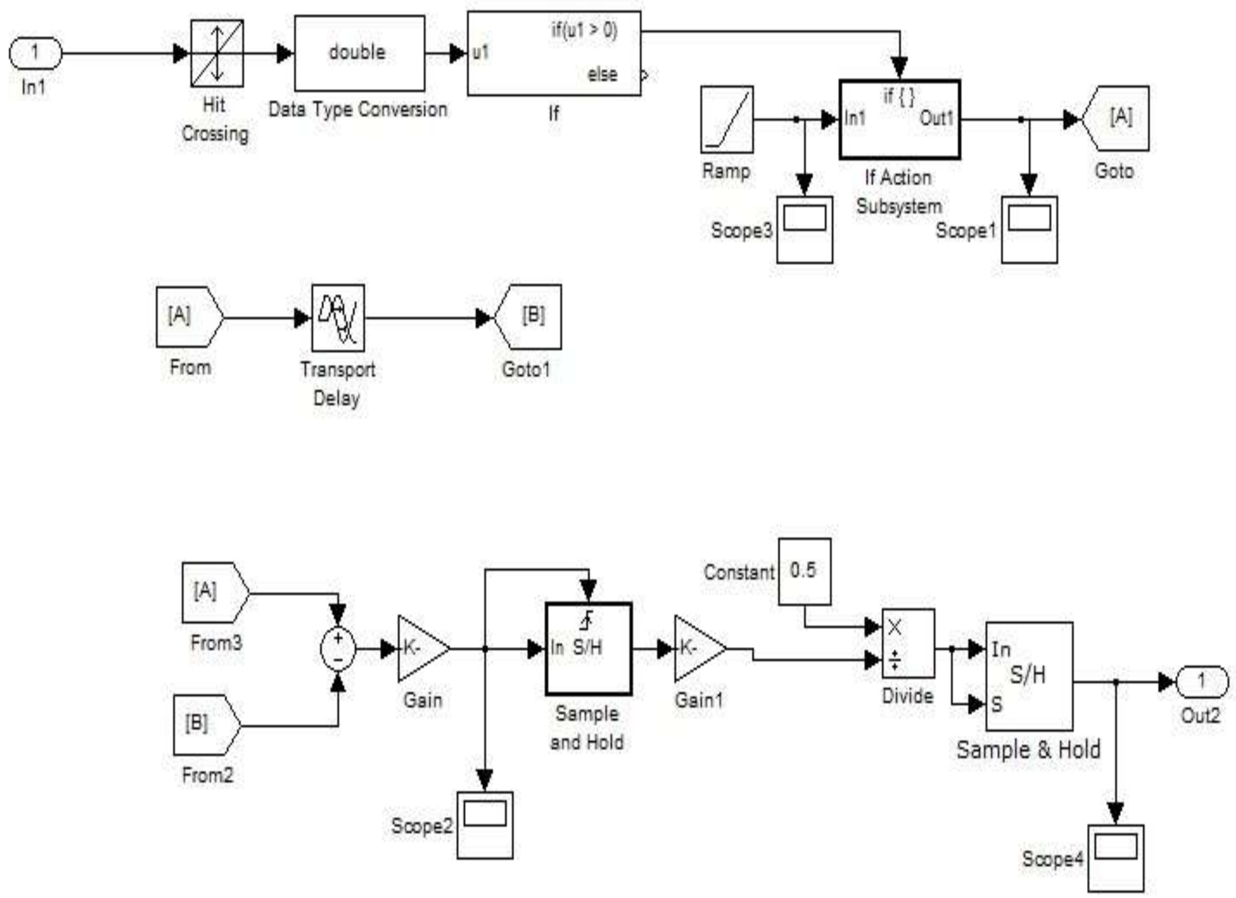


Fig. 3: Measuring Frequency of Voltage Signal on Simulink

'Hit Crossing' block is used to detect the zero crossing. The block passes the input signal at its zero crossings to the 'if' block, which in starts sending ramp signal to the output. The time duration of generated ramp is measured and saved to a variable 'A'. The variable A is stored in another variable B using the 'Transport Delay' block and the time of the next zero crossing is measured. Subtracting B from A at any instant will give half the time period whose value is held by the 'Sample and Hold' block, till the next zero crossing. After performing the necessary computations, given by Eqn. (13), the instantaneous frequency is achieved. The output (measured frequency) from FMU sends to the FDE for necessary tripping action, in case of fault.

B. FREQUENCY DETECTING ELEMENT

The FDE is used to take the necessary action in case of Over Frequency (OF) and Under Frequency (UF). The output from OF and UF are logically AND. The output of FDE or relay under normal case is set at 1, otherwise 0 (for tripping). The complete block diagram of the FDE is shown in Fig. 4.

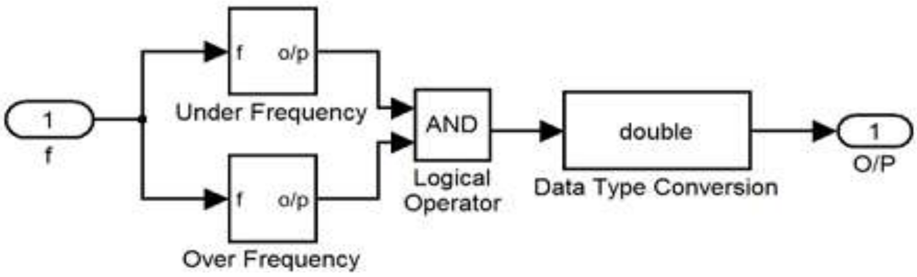


Fig. 4: Block Diagram Of Frequency Detection Element

The relay setting is given in Table 1. These limits are generalized and could be set to some other values based on country standards.

FREQUENCY RELAY SETTINGS

Nominal Frequency	Frequency Relay	Limit	Threshold Time
50	OF	51	5 sec
	UF	48.6	5 sec

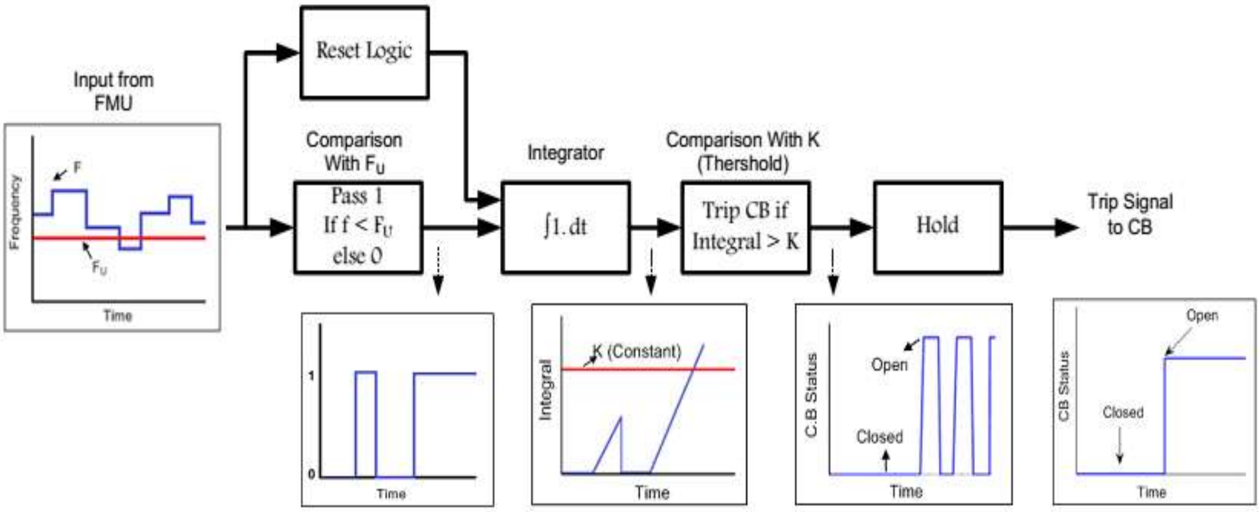


Fig. 5: Logic Diagram for Implementing under Frequency Block.

Fig.5 shows the logic diagram for the implementation of a frequency relay in case of an under-frequency situation. The frequency of the voltage signal is first measured by the frequency measuring unit (FMU) and then compared with the threshold under frequency limit i.e. Fu (48.6Hz). If under-frequency condition occurs, the measured frequency 'f' less than Fu), 1 will be sent to the integrator and integration will occur. The output of the integrator is then compared with the set value of K (5secs). If the integrator output exceeds the K value, the relay will trip. This is also a check to see the abnormality is transient or continuous. If the abnormality persists for K seconds the relay trips. Otherwise either integrator is reset by the reset logic or no integration occurs under normal conditions. Under normal condition, the integrator input is set at "0", thus the relay does not operate.

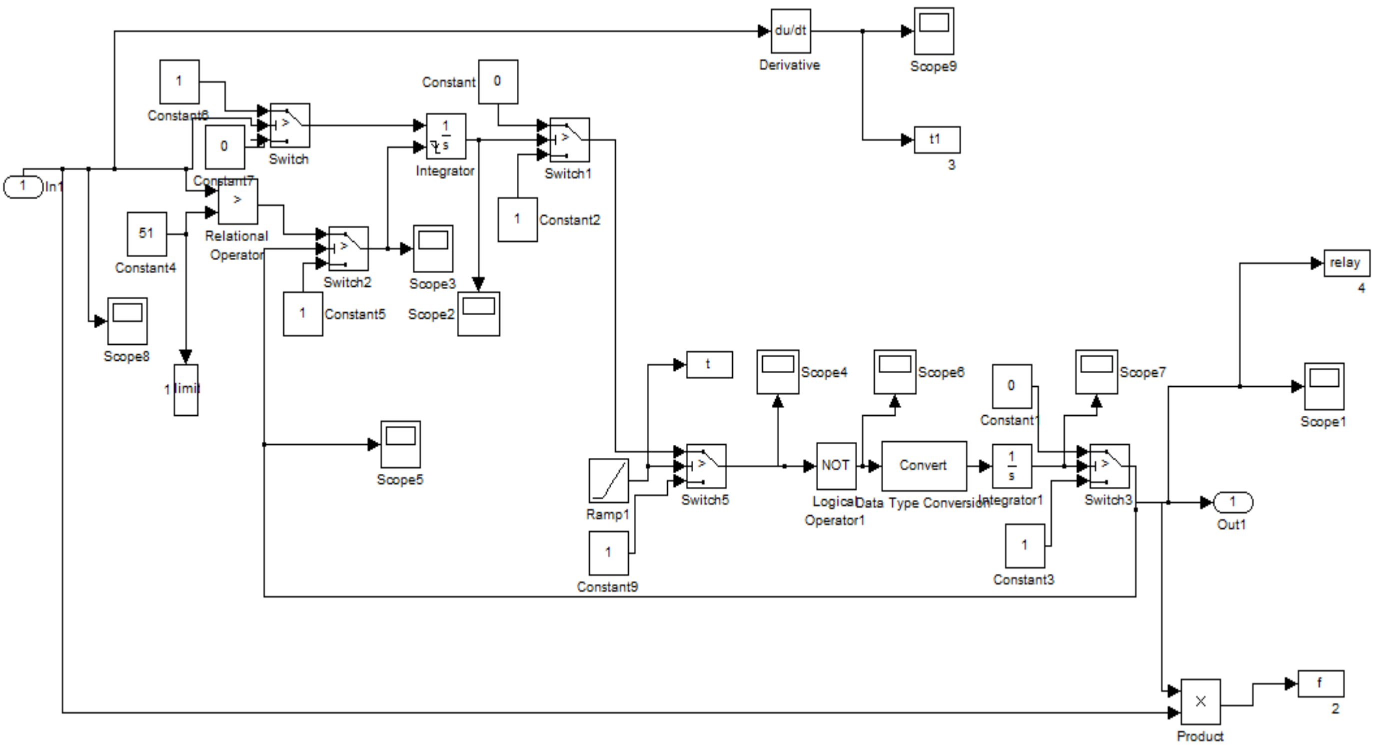


Fig : 6. Over Frequency Detection Block on SIMULINK.

For relay testing and simulation, a 132kV two bus network is considered. The single line diagram of the network is shown in Fig.7.

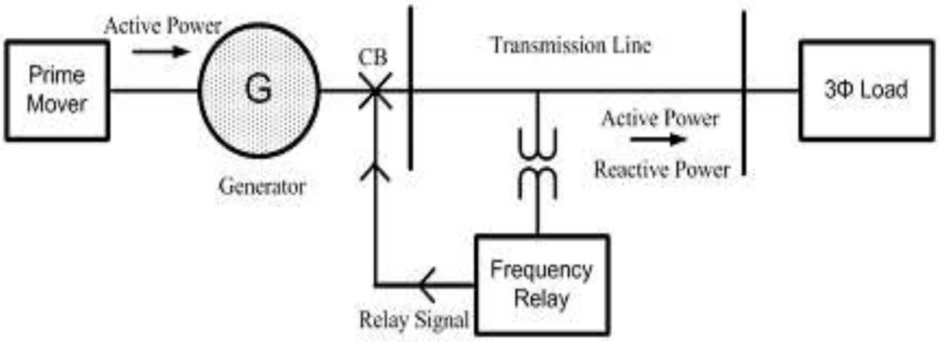


Fig. 7: Single Line Diagram of a Two Bus 132kV System

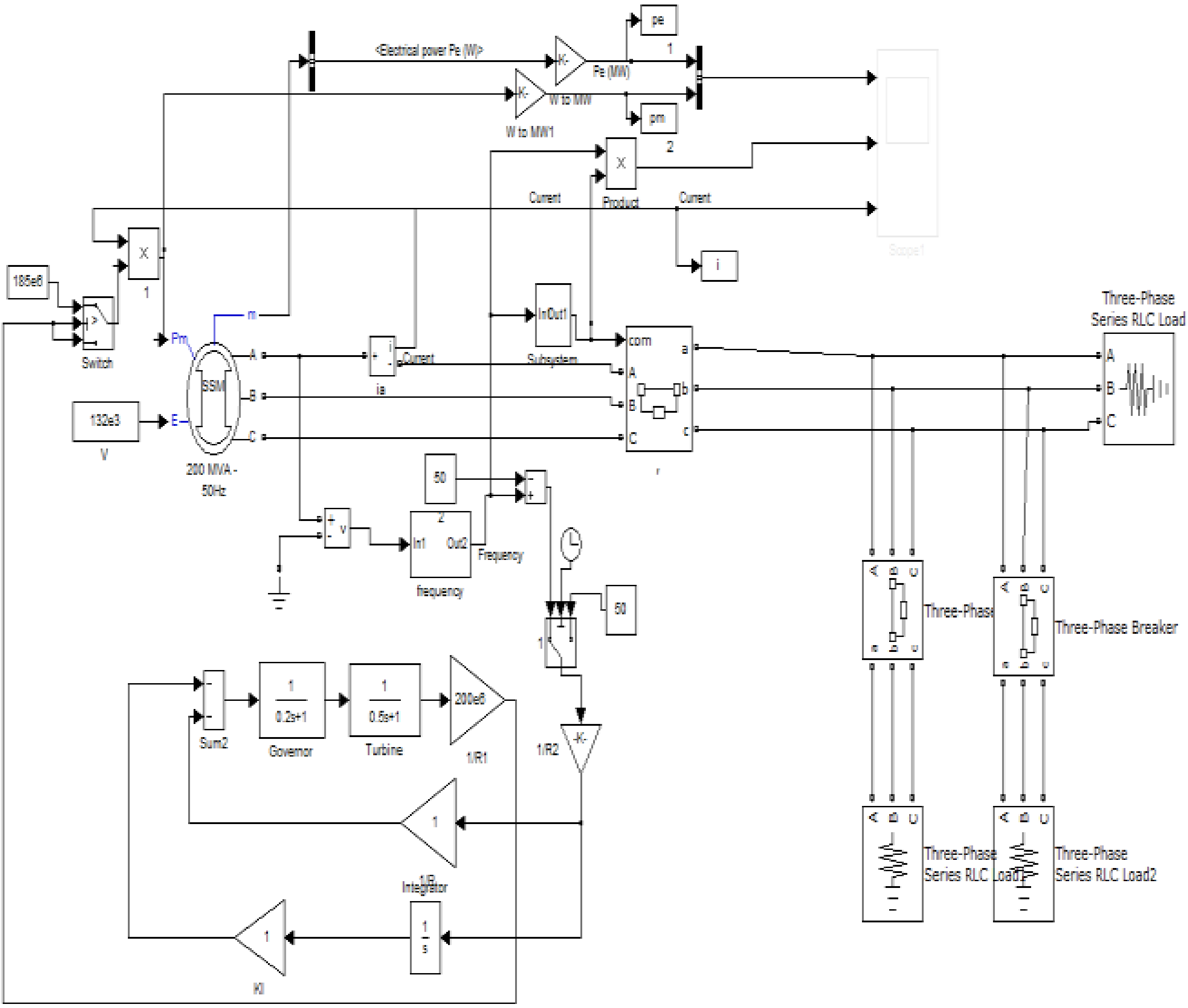


Fig. 8: 132kV System on SIMULINK.

IV. RESULTS

The relay is tested under different test conditions i.e steady state condition and transient condition during load shading. These tests conditions are given below. Cases1 is study state condition while case 2 is transient condition.

A. CONSIDERING ROTOR INERTIA

Although here we are talking about generator protection, So it will be a meaningless discussion if we are not considering the inertia of rotor. Practically we can't neglect inertia of rotor because the size of the generator is very large. In this we are neglecting the inertia of rotor.. Here we are discussing four cases under different load condition.

Case 1:

In this case, the load is shed in two stages. Initially from 190MW to 150MW at 0.5 sec, later on further load shed of 70MW is made at 0.7 sec and the relay behavior is observed. Fig.5.1(a) represents the current and relay status under different load conditions.

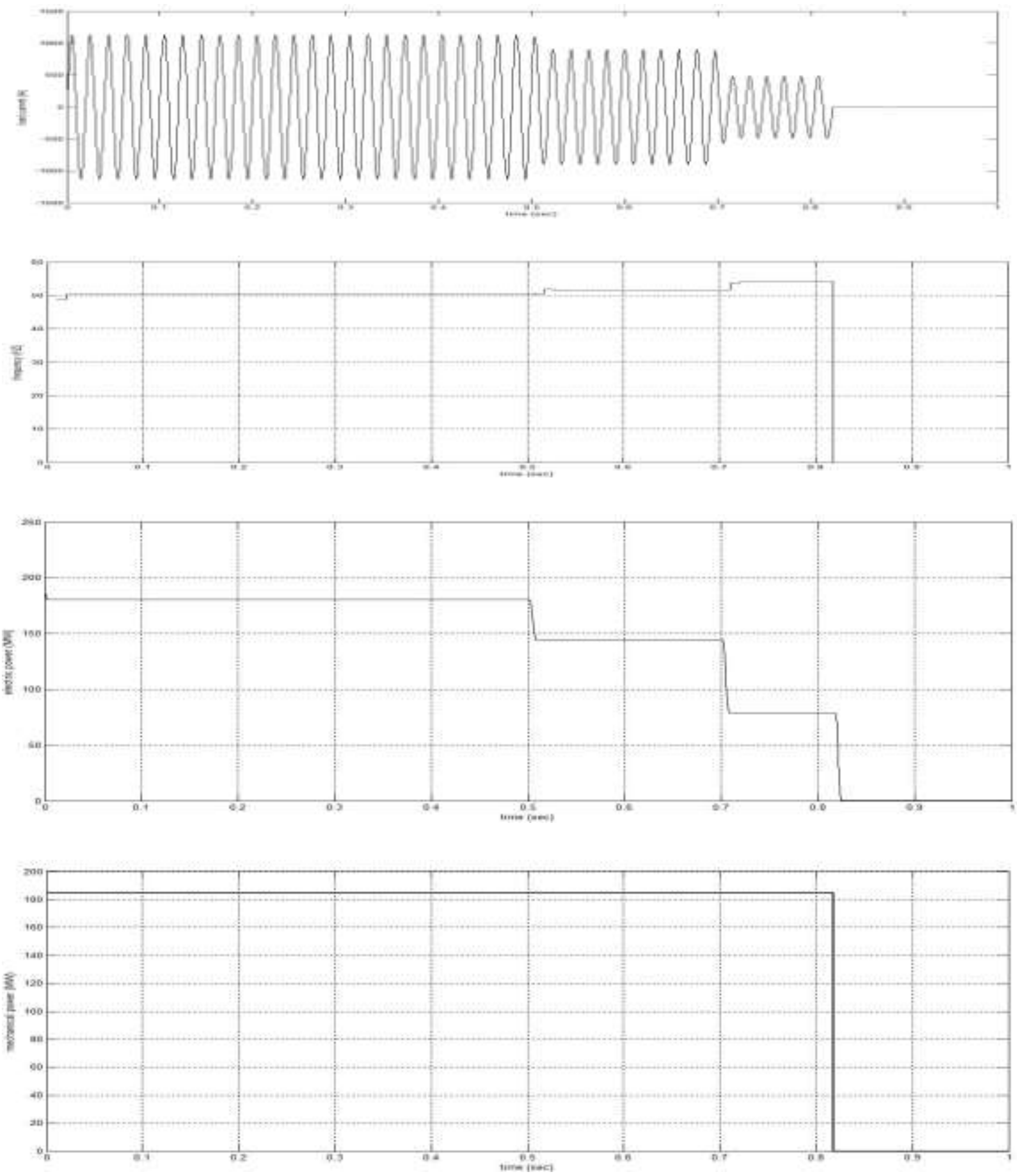


Fig. 5.1(a): case 1 load current (A) /frequency(HZ)/electrical/mechanical power(MW)vs time (sec).

Case 2:

In this case, the behavior of relay under transient condition is observed. One of the loads is momentarily disconnects and then restore, within 0.2 sec. In this case, the system load changes from 220MW to 140MW at 0.5sec, however at 0.7 sec, 80MW load restore. Fig.5.1 (b) represents the current and relay status under different load conditions.

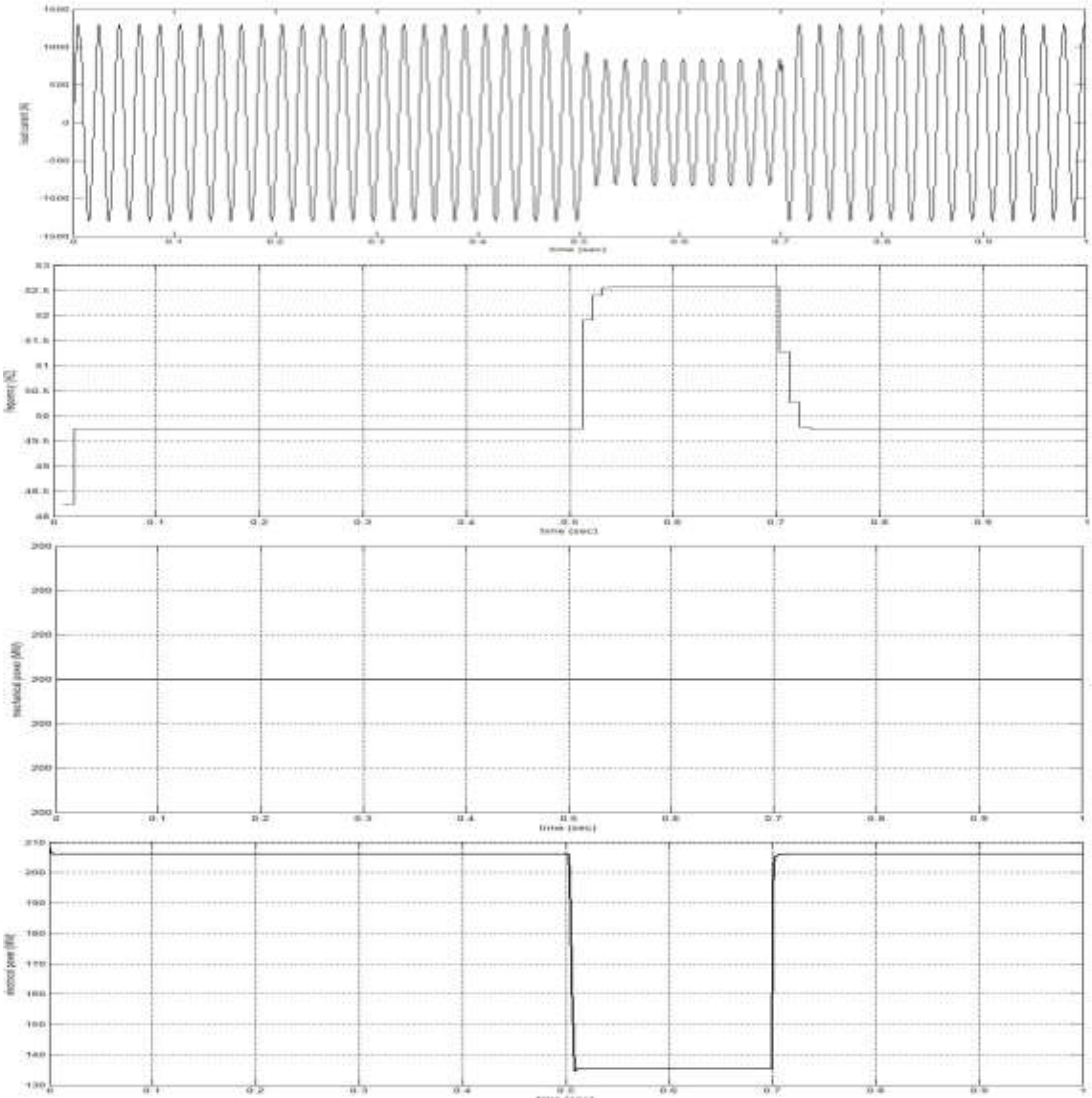
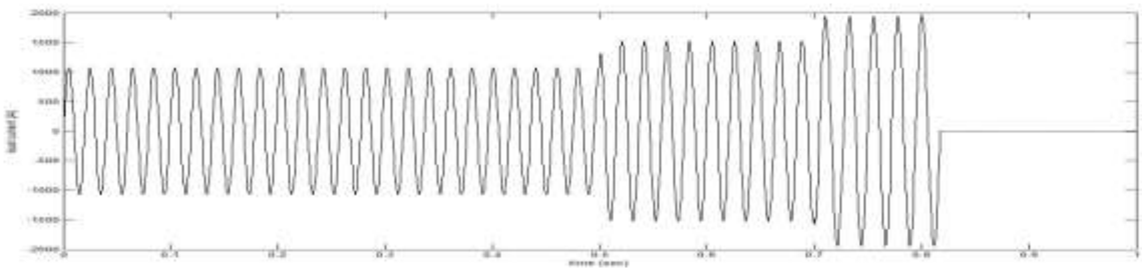


Fig. 5.1(b): Case 2load current (A) /frequency(HZ)/mechanical/electrical power(MW) vs time (sec).

Case 3:

In this case, 80MW is added at 0.5 sec in addition to base load of 180MW. Later on further load shed of 80MW is done at 0.7sec. Fig.5.1(c) represents the current and relay status under different load conditions.



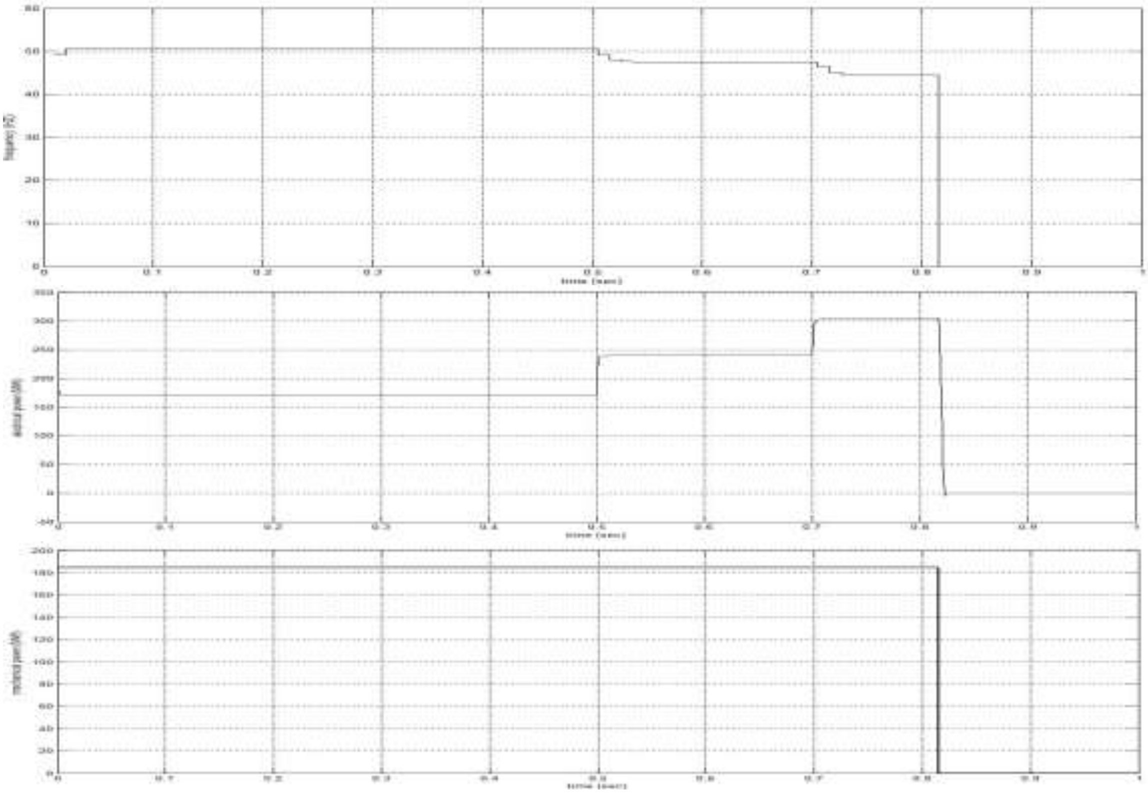
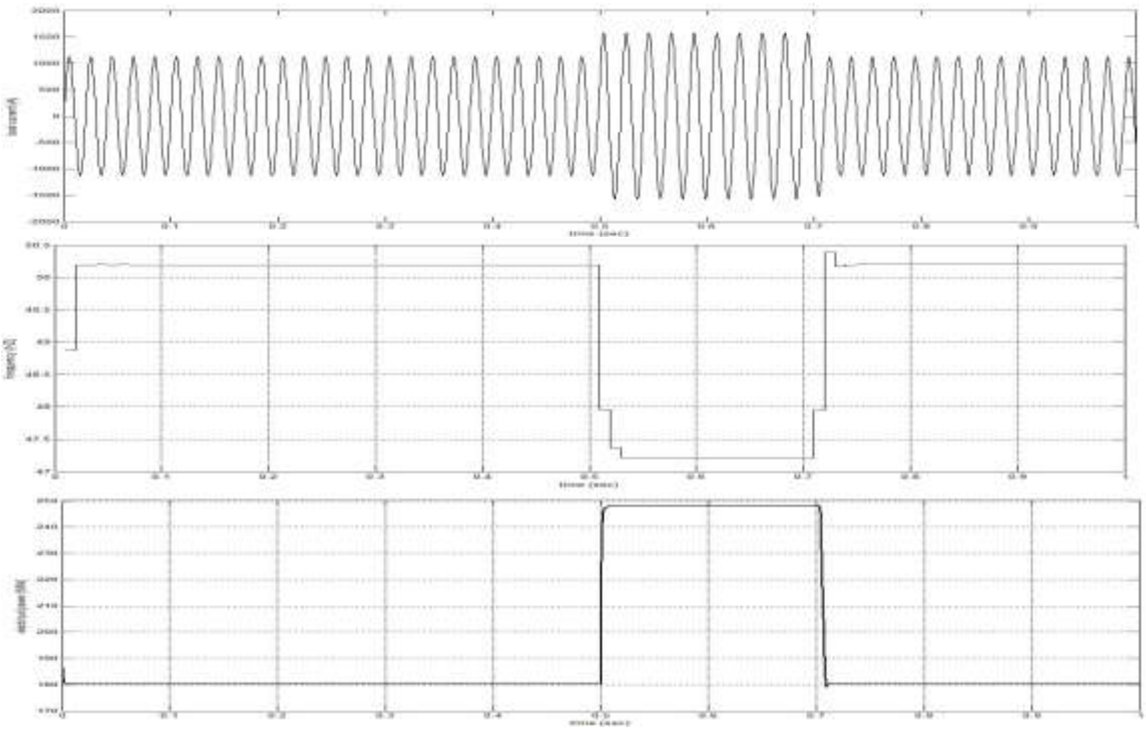


Fig. 5.1(c): Case 3 load current (A) /frequency(HZ)/electrical/mechanicalpower(MW) vs time (sec).

Case 4:

In this case, the behavior of relay under transient condition is observed. In this case, the system load changes from base load of 190MW to further addition of 80MW at 0.5 sec. However at 0.7 sec, 80MW load restore. Fig.5.1(d) represents the current and relay status under different load conditions.



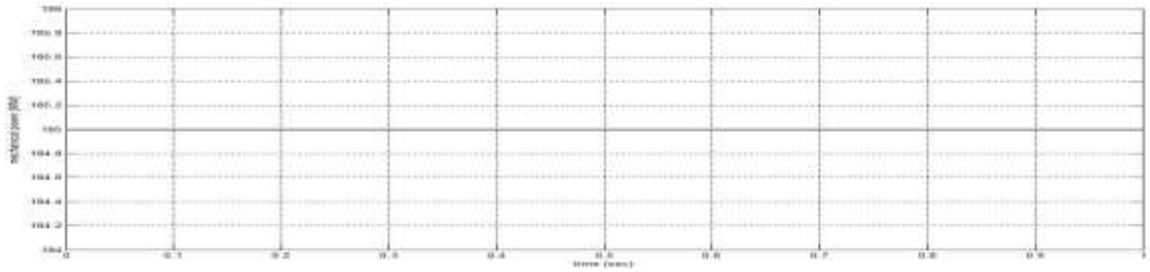


Fig. 5.1(d): Case 4 load current (A) /frequency (HZ) /electrical/mechanical power (MW) vs time (sec).

B. Neglecting Rotor Inertia

Here we all knows very well that for fraction of seconds inertia can be neglected. So all the performance is carried out within 1 second of time100 sec. and assuming the fault should be persist at least 5 sec for relay to distinguish whether it is a fault or any harmonic. So here also we are discussing four cases under different load condition.

Case 1:

In this case, the load is shed in two stages. Initially from 190MW to 150MW at 70 sec, later on further load shed of 70MW is made at 120 sec and the relay behavior is observed. Fig.5.2(a) represents the current and relay status under different load conditions.

Fig. 5.2(a): Case 1 load current (A) /frequency (HZ) /electrical/mechanical power (MW) vs time (sec).

Case 2:

In this case, the behavior of relay under transient condition is observed. One of the loads is momentarily disconnects and then restore, within 5 sec. In this case, the system load changes from 170MW to 90MW at 70sec, however at 75 sec, 80MW load restore.Fig.5.2(b) represents the current and relay status under different load conditions.

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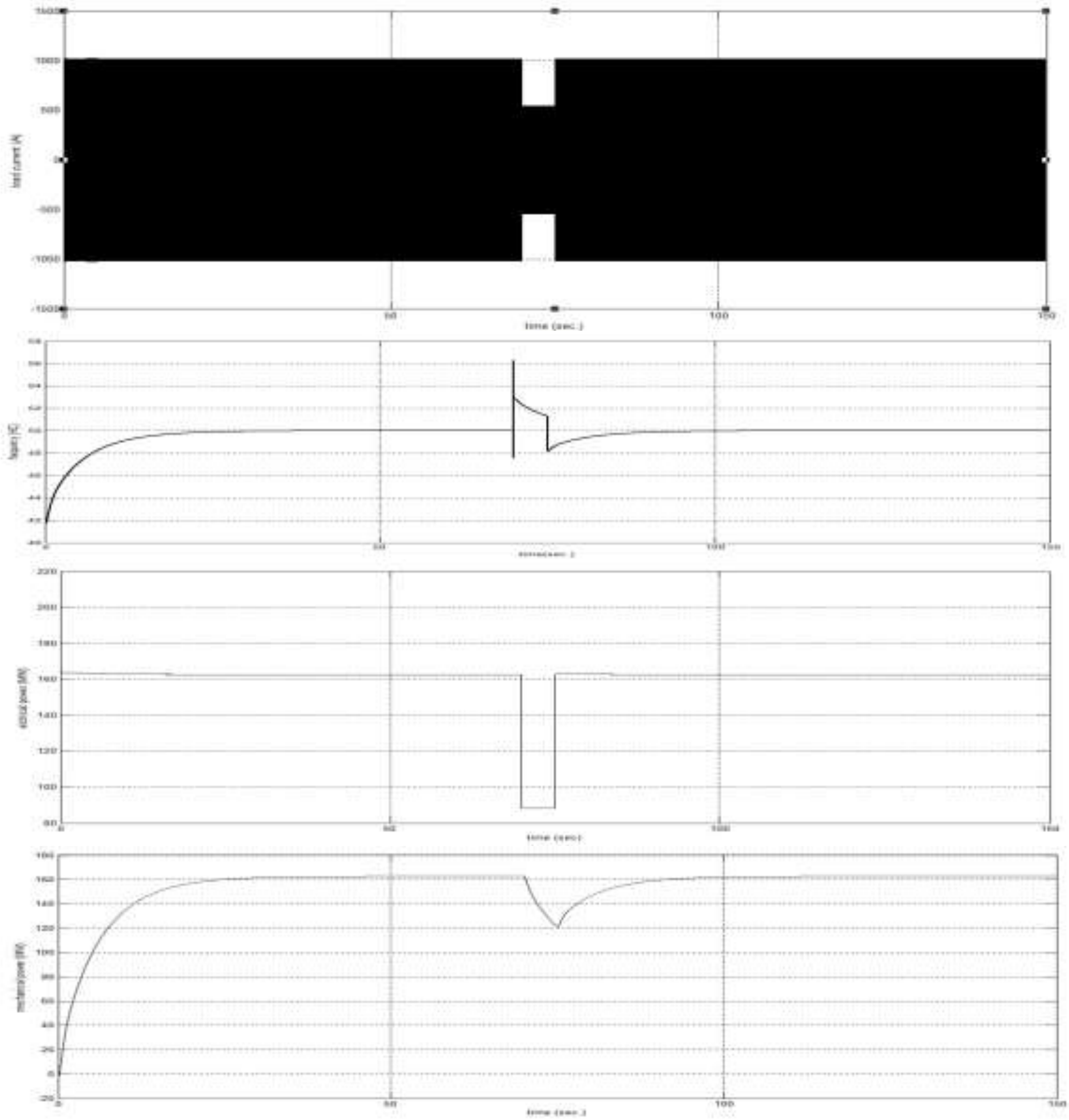
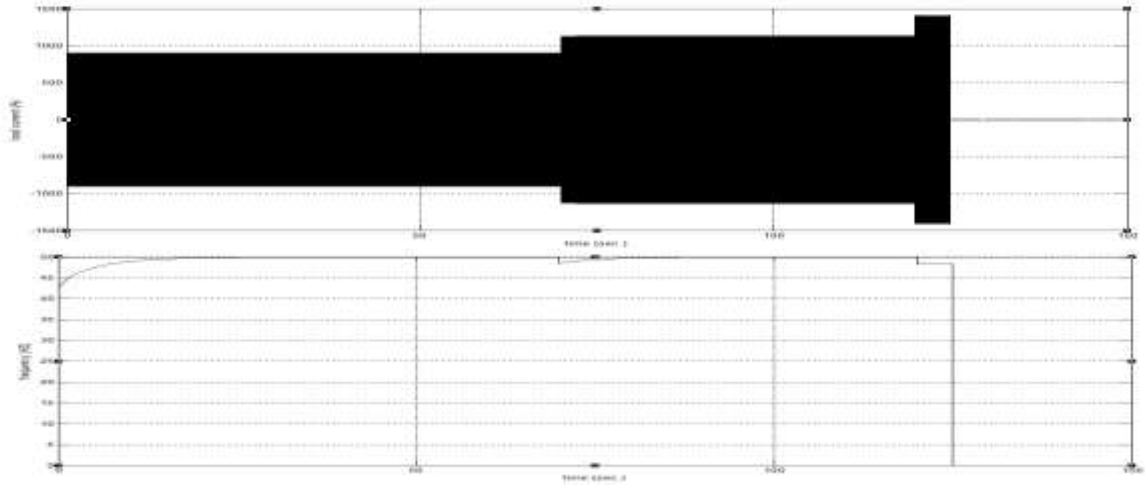


Fig. 5.2(b):Case 2 load current (A) /frequency (HZ) /electrical/mechanical power (MW) vs time (sec).

Case 3:

In this case, 40MW is added at 70 sec in addition to base load of 150MW. Later on further load shed of 50MW is done at 120sec. Fig.5.2(C) represents the current and relay status under different load conditions.



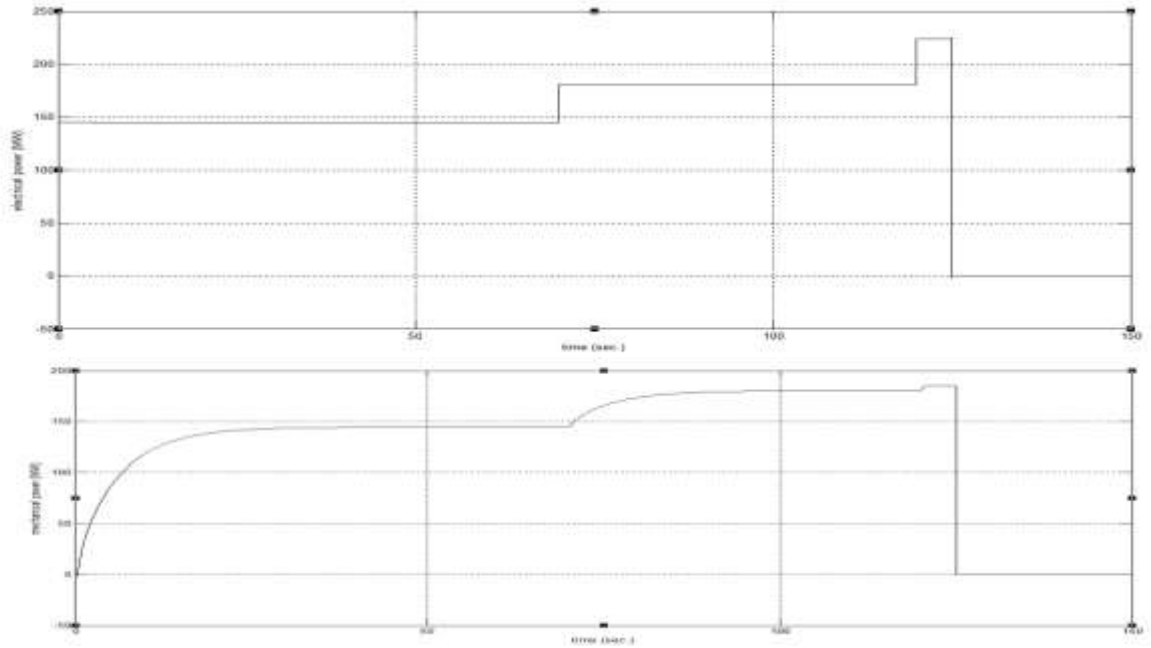


Fig. 5.2(c): Case 3 load current (A) /frequency (HZ) /electrical/mechanical power (MW) vs time (sec).

V. CONCLUSION

The paper has presented the modeling of the digital frequency relay on MATLAB/SIMULINK ®. The effectiveness of the proposed relay has been verified by considering different examples as case studies. The proposed model offer effective means for explaining the behaviours of over-under and under frequency relay under various operating conditions and changing the design parameters. The relay is more accurate as in digital relay there are only two state true and false or we say that yes or no. Logic 0 or 1 is used to operate the circuit breaker. Whereas in electro-mechanical relay, the relay may false trigger the circuit breaker due to over and under reach. But here in this type of relay there is no such type of condition because here it works any of two states. The digital relay has good advantage in terms of their sensitivity and wide range controlling.

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