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Design of Digital Reverse Power Relay Model for Generator Protection

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Abstract: Generators are one of the most important parts of the power system. Faults at the generator lead to severe failures and fatal accidents. Hence, generators' protection is a major concern, especially from faults – voltage and current fluctuations, short circuit faults, frequency variations, over-fluxing, flow of reverse power, etc. In this project, a protection scheme is presented for power flow in opposite direction that is flow of power from grid to the generator, due to which the generator starts consuming and acts as a load. Modelling tools are important to have a basic idea of power system. These tools aid an engineer to modify the system under all circumstances. This paper contains the simulation and modelling of digital reverse power relay in MATLAB/ Simulink®. The libraries in MATLAB offer Power System Analysis Toolbox which are simulation based, for power system engineering projects.
Keywords: Reverse power relays, Relay Modelling, Digital relays.

I. INTRODUCTION

In power systems, for detection of synchronous generator's motoring action, reverse power relays are used. When the field winding is connected electrically with the system of excitation but the prime mover failure occurs. Thus, the machine behaves like a synchronous motor, connected with enormous power system.
In such conditions, the rotors behave like the active load on that machine. Motoring action eats power to rotate the prime mover and severe damage is caused to the prime mover. It is a dangerous condition since there is an objectionable rise in temperature, especially for steam turbines.
Therefore, these must be detected immediately and the GCB should be tripped. Electromechanical relays are replaced with digital relays which are highly accurate and have high-speed operations. Fast operation of relay is a must, especially for faults which may result in system shutdown. Some additional perks of digital relays are - multiple variable settings, highly sensitive, control for a wide range and compact size.

II. OPERATING PRINCIPLE OF REVERSE POWER RELAY

Directional relays that is used to check the power flowing from generator (operating in parallel with another generator/utility) and take proper actions accordingly. Under certain conditions, the direction of power changes from the bus bar towards the generator. This generally happens when prime mover is unsuccessful. The grid-extracted active power is relatively small compared with the generator rating. To obtain the reverse power relay modelling, it has been organized into sections, namely - directional element, delay element and hold block.

III. PRIME MOVER FAILURE FAULT OR REVERSE POWER FAULT

A generator is incorporated with prime mover and is connected with the grid, yielding power. When the failure of the synchronized prime mover occurs, the condition is known as motoring. Here, the generator pulls power from the bus, operates like a motor and drives the prime mover.
In a synchronized condition, frequency of all the generators is same. Any dip in frequency of one alternator causes the other sources of power to feed power into the alternator. This power flow in the opposite direction is called reverse power flow or motoring action of alternator. Another incident of reverse power occurs during synchronization. When the frequency of bus bar, which is also the machine synchronization frequency, is slightly greater than machine frequency and the breaker is OFF, power flows from the bus bar to the machine.

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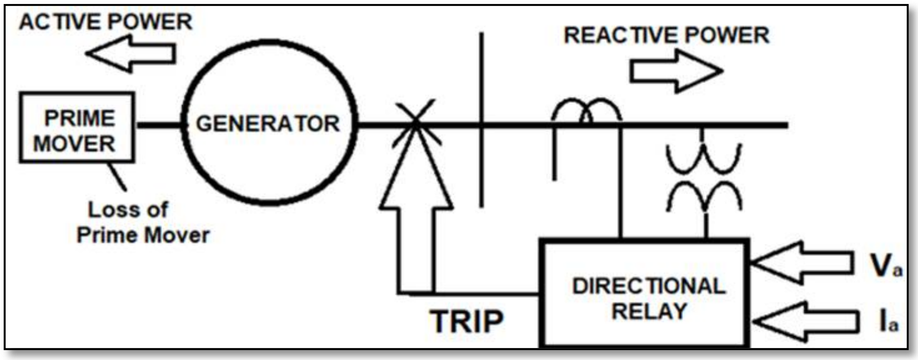

Fig. 1. Reverse Power Flow

Hence, during synchronization, the machine frequency is kept little more than that of the bus bar. This allows the machine to take load the moment the breaker closes. A reverse power relay can be used but it must have a time delay setting to ensure correct trip in case of short time fluctuations, phase swings and disturbed synchronization. Hence, when a power reversal issue occurs, the first thing is to decouple the corresponding alternator from live line with the help of the breaker. If it is stuck, then whole bus needs to be shut down.

IV. REVERSE POWER RELAY

Reverse Power Relays (RPR) are used to sense motoring operation of synchronous alternators. The RPR is a protective directional relay that restricts power to flow in the opposite direction. It is used in installations where a generator functions in parallel with other generator or the utility in order to prevent power to flow again into the first generator when it fails the output. The relay checks power from the generator and in case of output falling below a specific value, it immediately decouples the coil of the generator to avoid power from entering the stator coil. The generator output fails because of the prime mover issues, speed controller problems, turbine that runs the generator, or varied frequencies during synchronization. The RPR senses power flow in reverse direction and separates the generator to reduce damage up to a great extent.

V. MATLAB/SIMULINK® MODELLING

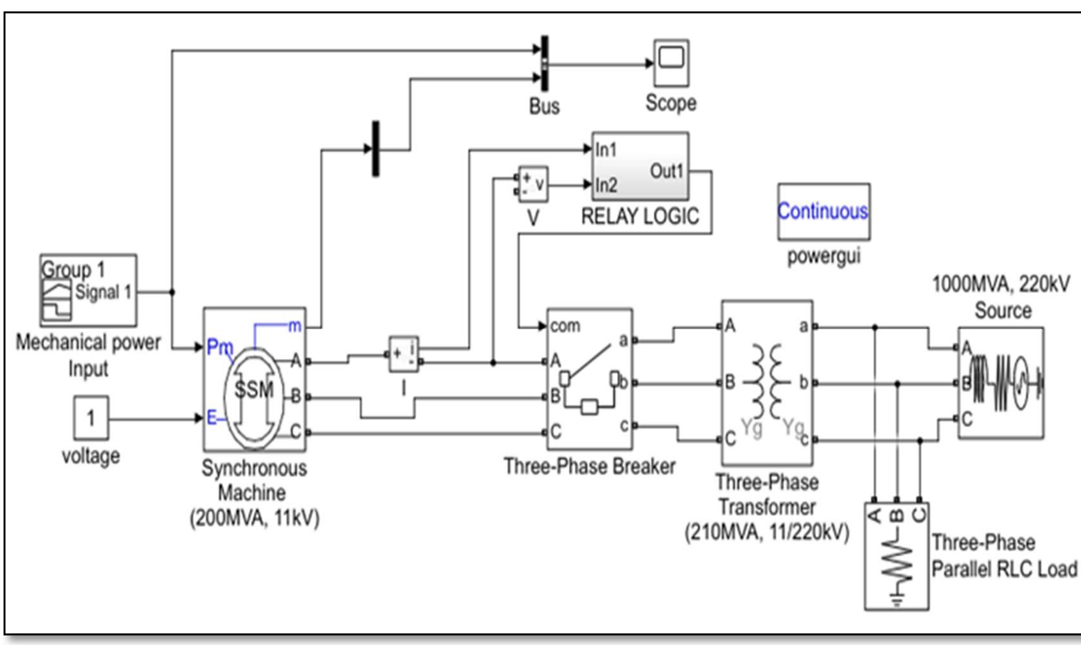

Fig. 2. The proposed scheme

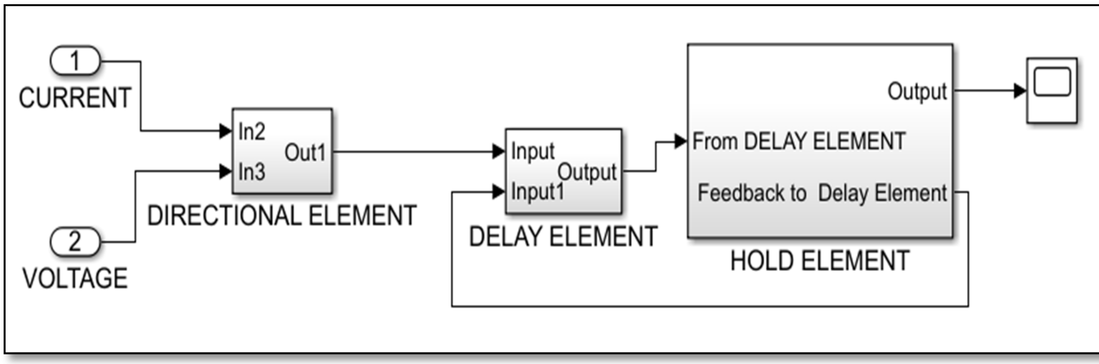

Fig. 3. Relay Logic Subsystem

A. Directional Element

For directional element, a low voltage signal from PT and current signal from CT are converted in perfect square waves with values +1 to -1. This means, ‘switch’ and ‘switch1’ output in the form of square wave and not touching zero. Later, these waves are multiplied to yield ‘1’ as an output during the overlapping and ‘-1’ during the non-overlapping interval.

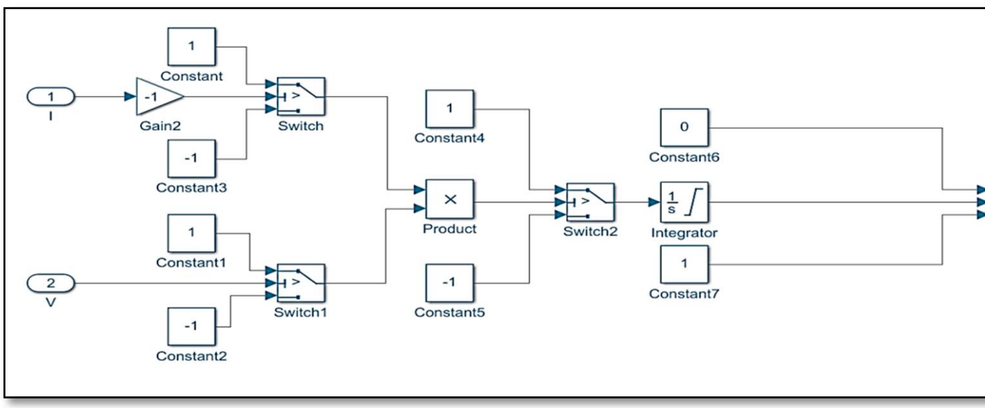

Fig. 4. Directional Element

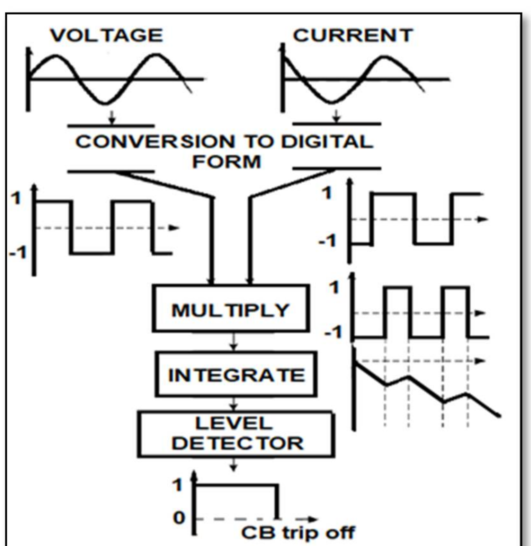

Fig. 5. Implementation of Directional Element

That is switch 2 output is:

- 1 for overlapping = normal condition
- -1 for non-overlapping = abnormal condition

Then the product is integrated from 'L' to '-L'. To keep the integral always less than '0' under normal circumstances of load flow, the higher integrator limit is set at '0' value.

However, the output of integrator tends to drop till it touches a threshold value 'L', under power flow reversal scenarios. That is, more the overlapping condition, more the value of integral that is positive ('0' here) indicating healthy condition. And if the overlapping condition is a short span, the value of negative integral will be lower. When the threshold value '-L' is crossed, trip signal travels from relay to breaker. This is why, L is 0.01, but values can be set depending upon how severe is the reverse power.

B. Delay Element

The job of the delay section is to avoid the relay from passing any false trip signals to the breaker during temporary faults or transients. The directional element output is fed to delay element decision block with output '0' when normal and output '1' when abnormal conditions occur. This output is then integrated and the value of the integral is compared to the threshold level 'T', whose value is set equal to the delay time desired.

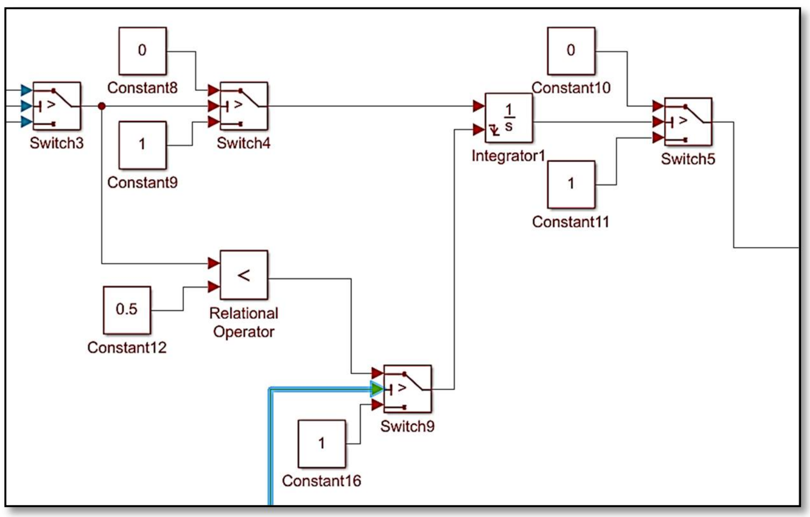

Fig. 6. Delay Element

When,

- Healthy conditions – integral value < T - delay element output is '1'.
  Under steady conditions, the integrator input is '0'. Therefore, the integrator value is '0' always (< T), and so the delay element output is 1.
- Unhealthy condition - the integral value > T, delay element output is '0'.
  The integrator input is '1' and 'T' seconds later, faulty condition is indicated through obtained integral value.
- Transients or a temporary fault - for < 'T' seconds, the integrator value is back to '0' with the help of relational operator after fault clearing.

C. Hold Element

The hold block maintains the status of the relay, 'stable' after the relay tripping. Since, once the CB has opened, the fault will stop existing, faking a normal condition and pushing the relay to again pass a '1' signal to the CB, causing it to close again. The '0' value from the delay block is integrated after getting inverted.

If the integral value exceeds '0', the output of the hold block switches to '0' from '1'. But the integrator cannot reset here. So, once the integral exceeds its threshold i.e., '0' it never returns to the value. Thus, the hold block output is '0', always. There is a switch block between hold element and delay element, which is used solely to stop the relay from false tripping during transient periods.

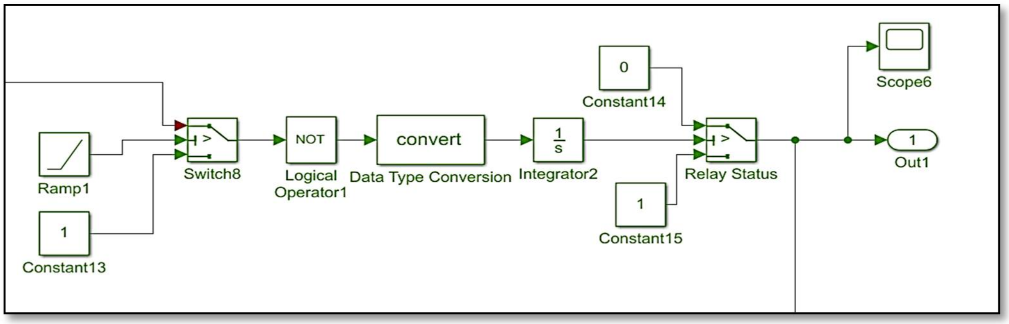

Fig. 7. Hold Element

VI. OVERALL CIRCUIT

The functioning of the complete circuit is interesting; however, has a chain of signals inter-related with a feedback path at the final stage. The directional block converts all the signals into perfect square waves and also analyses the overlaps and non-overlaps in power waveform. The power signal is then integrated and output is given as input to the delay block. The delay block merely provides a delay of certain time instant so that blackouts can be avoided during transients. In this instance, we have provided a delay of 9 seconds. The block has two major elements- the relational operator and Switch 4.

During normal conditions, Switch 4 functions. When a fault occurs, the relational operator works instead of Switch 4. The relational operator obtains feedback from output which enables delay block to provide proper delay and the hold block to hold the status of each element until the fault is cleared. The hold block involves of a logical operator NOT. When a fault occurs and the circuit breaker opens, the initial circuit up to the hold integrator 2 feels that the conditions have normalised since reverse power stops to flow. Hence, all the initial elements have a tendency to reverse their status. NOT keeps the faulty status maintained till actually the fault clears. The output of hold block yields the relay status which is ‘1’ in normal conditions and goes down to ‘0’ during abnormal conditions.

VII. OUTPUTS

A. Generator Power

The mechanical input to the generator changes from 0.6pu to 0.8pu at 25s. And further keeps on oscillating at different time instants. However, at 75s it is observed that output electrical power goes negative for a very short instant, this is where transient occurs. Later, at 100s actually the fault has occurred. Thus, power flows in reverse direction.

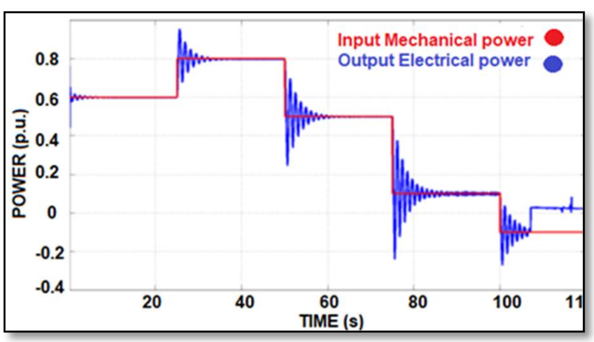

Fig.8. Generator power

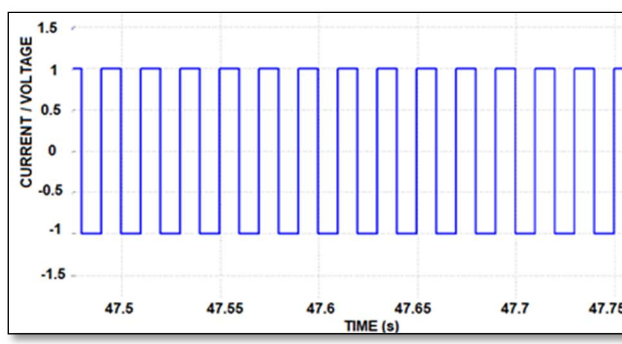

Fig. 9 Current/Voltage Input

B. Directional Block Signals

At 100s, the reverse power flows, hence, it is observed that the overlapping width that is of magnitude ‘1’ is getting narrower where current and voltage signals seem to go out of phase gradually. This is the input signal given to the directional element integrator which integrates from ‘0’ to ‘-L’. The integrator integrates the power signal and keeps it ‘0’ for normal conditions. As soon as reverse power starts to flow as 100s, integration values appear. It is observed that the directional block experiences transient condition where it changes its status from ’1’ to ‘0’. But soon the condition is normalized and status returns to ‘1’. At 100s, when fault occurs, it sets its value to ‘0’, this time indicating an actual faulty condition.

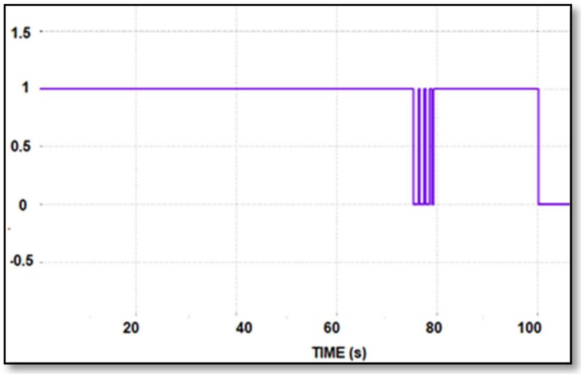

Fig. 10 Directional Block Output

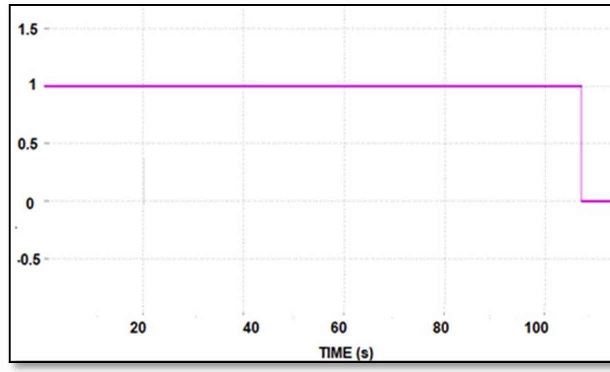

Fig. 11 Delay Block Output

C. *Delay Block Signals*

Here, status '1' is normal condition. The fault occurs at 100 seconds. But since the 9 seconds delay setting is present, the delay block waits for 9 seconds and then an output value '0' indicates that the fault has occurred.

D. *Hold Block Elements*

The integral component in the hold block follows the delay block and after a 9 seconds delay, it starts integrating the values as shown above.

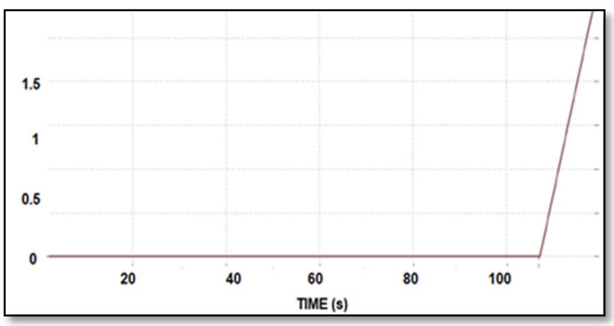

Fig. 12 Hold Block Output

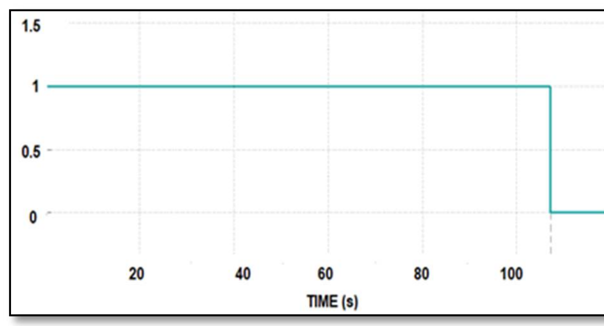

Fig. 13 Relay Status

Finally, it can be observed that the system operates safely during all mechanical transients and smoothly isolates the generator at 109 seconds, when mechanical input loss occurs. The relay status '1' indicates healthy conditions. When at 100 seconds the fault occurs, the system checks it for 9 seconds and thus gives a trip signal to the circuit breaker as relay status changes to '0' indicating actual occurrence of fault.

VIII. CONCLUSION

The work investigates the reverse power condition of the generators in power plants. The relays are able to detect disturbances and when these occur, all digital and analogue signals are stored in its memory, including the pre-fault, fault and post-fault intervals.

The paper is about the simulation of digital reverse power relays using MATLAB/ Simulink®. The proposed relay model is depicted by taking into account different case studies. The digitization process of electrical quantities is also discussed in details. As compared to other power relay model in existing power system software, MATLAB offers advantage in terms of their accuracy, ease of settings and flexibility. Further, it can be modified the testing parameters as well as the design of the relay.

A variety of schemes for protection can be accomplished with significant improvements in relay logics. High speed-tripping time of half cycle or less can be obtained along with multiple variable settings. Greater sensitivity and high pick-up ratio will not only enable wide range controlling but also facilitate smooth and safe operations of the power system. Similar to reverse power relay logic developed in this project, a number of other logics can be designed based on different power system faults. The whole scheme can be implemented in hardware using analogue and digital circuits. The thresholds can be varied and set according to the fault and protection scheme. More advanced digitalisation processes and technological principles can be implemented to form complex multi-functional, multi-fault protection schemes.

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