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MODELING AND SIMULATION OF DIGITAL REVERSE POWER RELAY

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Abstract

The protection of power systems always attains greater importance; presence of distributed generators (DG's) in the event of faults, protection engineers has to take utmost focus on it. Most of the traditional practices to design protection relays were electromechanical later replaced with solid state relays, presently both are replaced with digital relays intended better accuracy, high speed and reliable operation of power system protection. In this paper the digital reverse power relay is modeled, simulated to detect the reverse power in the event of faults on MATLAB/Simulink®. Diverse modeling statistics adaptation steps in digitization of a signal are also discussed. Finally, the relay performance is tested on 11kV synchronous generator with presence of microturbine DG connected with 220kV.

Keywords: *Distributed Generator (DG), Micro Turbine, Faults, Bidirectional Power Flows, Reverse Power Relay.*

1. Introduction

Protection relays play a very important role in the safe and reliable operation of power system. Insecure or failed

Protection systems may make the situation worse and lead to the system blackouts. All faulted conditions do not lead to such situations. Faults that cause such situations include N-1 contingency of line, overloads, reverse power flow (loss of mechanical input) and others [1]. A typical protection scheme is an arrangement of various types of relays such as over current, short circuit relay, over-under voltage, over-under frequency relays and others. In 90's, most of the relays in power system were electromechanical, later on replaced with solid-state. Now both types of relays are being replaced with digital relays. Digitals relays offer advantage of fast in operation, small in size and reliable in operation in case of power system fault [2-3]. The relay also offers advantage in terms of their sensitivity and wide range controlling.
Simulation tools offer great help particularly for fresh engineers and researchers to familiarize with real operation of power system [4]. As a researcher, the behavior of the system could be seen under different scenarios and results could be manipulated, which is not possible in healthy system. MATLAB also offers simulation based Power System Analysis Toolbox for power system engineers. However this toolbox does not have protection relays modules. In this paper, the design of a digital Reverse Power Relay (RPR) is constructed on MATLAB/Simulink®. Several digitization process also include in signal processing. Such steps are also discussed in this paper.

2. PROBLEM FORMULATION

Presence of micro turbine DG in the event of faults in distribution system performance in protection aspects will influence by the bidirectional power flow in this section micro turbine is modeled, a quick review on causes of reverse power and its impacts on distribution system is described.

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2.1 MICRO-TURBINE MODELING

To drive the compressor mechanical power is needed which is evaluated by following equation [5-8],

$$Pc = \frac{1}{\eta_{th,c}} m'cCp\left[PRc\left(\frac{\gamma - 1}{\gamma} \right) - 1 \right] T_{in-c} \quad (1)$$

Where the input temperature (K) is Tin_c, Pressure ratio of compressor is PRc, mass flow rate of compressor(g/s) is m'c, specific heat ratio of air is γ, thermal efficiency of compressor is ɳth, c, specific heat ratio of air (KJ/kg,K) is Cp and mass flow of compressor(g/s) is m'c

The output mechanical power of turbine can be calculated

$$Pt = \left\{ \eta_t \left[PR_t \left(\frac{\gamma - 1}{\gamma} \right) \right] T_b \sum \left(NpCp(T_b) m_p \right) \right\} \quad (2)$$

Where, the turbine temperature of turbine is (K) Tb, turbine pressure ratio of turbine is PRt , the specific heat of produced is Cp in the burner which is a function of temperature (KJ/kg.K), mp is the mass flow rate of the product (g/s).

2.2 CAUSES OF POWER REVERSALS

Though utmost cares have been taken at the incident distributed generators being integrated, still there are certain conditions opens the probability of bidirectional power flows in the event of system faults which are summarized as follows.

- In the process of matching the grid code criteria if the fault is incepted, cause for slightly variations in frequency between DG sources to be integrated with busbar.
- The instant at which evaluation of voltage levels and power flows in the distribution system (or) grid presence of DG sources will impact if localized over voltage is occurs.
- To stop ‘upstream’ current flow in the distribution network protection devices are designed and incorporated.

2.3 IMPACTS OF POWER REVERSALS ON DISTRIBUTION SYSTEM

- The distribution grids are not designed for sudden change of the energy production paradigm. As a consequence of DG sources integration leads to the following dynamics.
- Having negative impacts on end-use equipment
- Destabilizations of voltage regulators’ because they are not designed for bidirectional power flow.
- Power reversal enforces the system in unbalanced condition.
- Protection issues.
- Grid stability problem, transformer reverse power flow, voltage rise, unexpected islanding operations, sympathetic tripping, etc.

To give protection above illustrated causes in power distribution system digital reverse power relay is designed, modeled and simulated at various conditions as follows.

2.2 REVERSE POWER RELAY

To detect the power flow direction In the event of fault in the prime over (or) DG source directional over current relay called reverse power relay is used, this condition facilitates the motoring operation and machine is transited as synchronous motor coupled to distribution system. Consequently the turbine turn into active power load connected to the machine and power drawn from the system due to motoring action anticipated by the machine will pose severe damage to the prime mover. As early as possible these condition has to detect to avoid further issues caused by the excess heat induced in this process, and the GCB should be tripped [9]. Diesel engines and gas turbines are less susceptible to immediate damage, but unburned fuel may present a fire or explosion hazard.

To detect the bidirectional power flow which may be caused by the inception of fault in DG source or failure of prime mover needs to find two parameters (1) Reverse power trip level (2) Time delay

For secure function reverse Power Trip Level:

Trip Level < No load loss of TG unit * 0.3

= 3,135 * 0.3 = 940.5 KW

Pick up = Trip level / relay constant

= 941 / 440= 0.0021 pu

Setting = - 0.0021 pu (924kW)

Reverse Power Trip Delay

Trip Delay < Permissible Motoring time

Setting = 750 Cycles for 50Hz system (15 Sec)

Power reversal condition in distribution system emerged due to frequency difference followed by the instant CB closed between DG source (Less) which is going to integrate and bus bar (High).This ensures that the machine takes on load as soon as the breaker is closed [10].

In the event of fault inception RPR is also uses islanding detection. The condition at which unbalanced condition is exist between load and amount of generation (grid plus DG capacity) to obtain an substantial rate of change of frequency but the active power continues to flow into the grid to supply external loads, RPR with UF can be used to detect loss of grid supply [11]. The other applications of reverse power relay could be seen in [12].

3. PRINCIPLE OF REVERSE POWER RELAY

Directional over current relay (or) reverse power relay is used to detect the power flow direction in distribution system presence of distributed generation in the event of faults. Based on the power direction during normal and abnormal condition RPR is detecting the power flow and intimate the CB to take necessary action.

The active power drawn from the grid is relatively small compared with the rating of generator. However stator current undergoes 180" phase shift usually referred as Maximum Torque Angle (MTA) as shown in Fig. 1.

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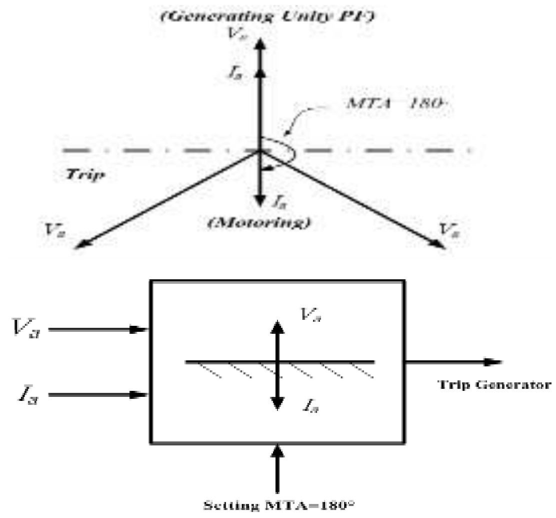

Figure1. (a) Phasor Representation (b) Block Representation of Current and Voltages under Reverse Power Flow

This suggests that if we use a directional relay with MTA of 180" (using generator phase angle conventions) then it could detect the loss of prime mover as the current phasor would reverse and enter the trip region. However the magnitude of this reversed current phasor is relatively small compared to the forward current as the generator draws just adequate active power to assemble the losses and drive the turbine. Hence, the directional relay for detecting the loss of prime mover needs to have a high degree of sensitivity compared to directional relays used for over-current application [13].

The installation of RPR on a power system is shown in Fig. 2. For applications where a protection sensitivity of better than 3% is required, a metering class CT should be employed to avoid incorrect protection behavior due to CT phase angle errors when the generator supplies a significant level of reactive power at close to zero power-factor. The reverse power protection should be provided with a definite time delay on operation to prevent spurious operation with transient power swings that may arise following synchronization or in the event of a power transmission system disturbance [14]

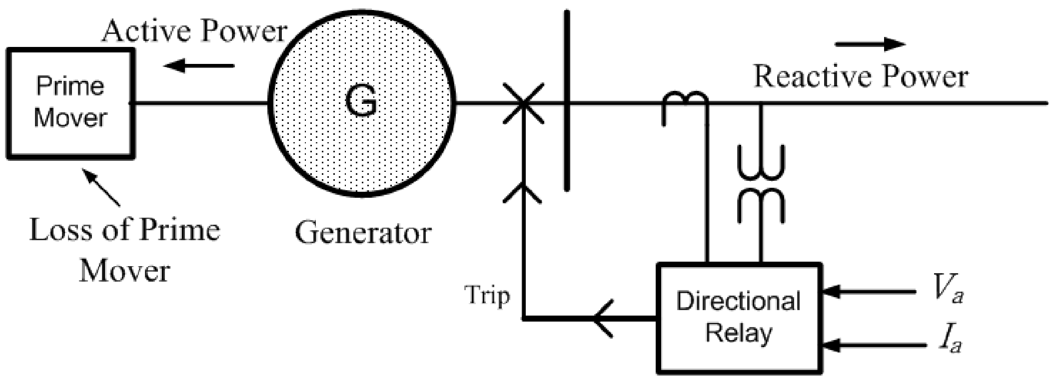

Figure 2 Reverse Power Relay in Power System

Let ‘δ’ is the angle between current and voltage on phase A, then under normal direction of load flow -90o < δ < 90o and in case of reversed power flow +90o < δ < 270o [15].

From the careful observation in the event of normal operation between voltage and current the time span of overlapping period is higher than the non overlapping period as shown in Fig. 3a. However this overlapping reduces to a low level in case of reverse power flow, shown in Fig. 3b.

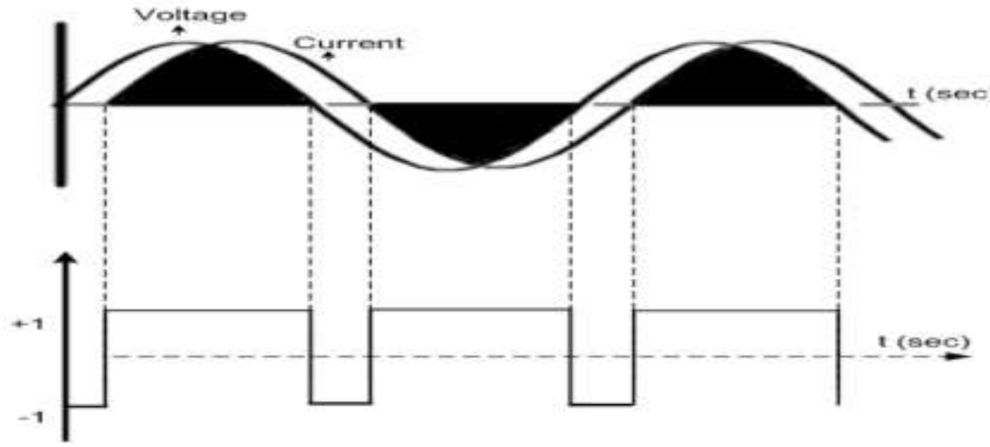

Figure 3aAngle between Voltage and Current Waveforms under Normal Conditions

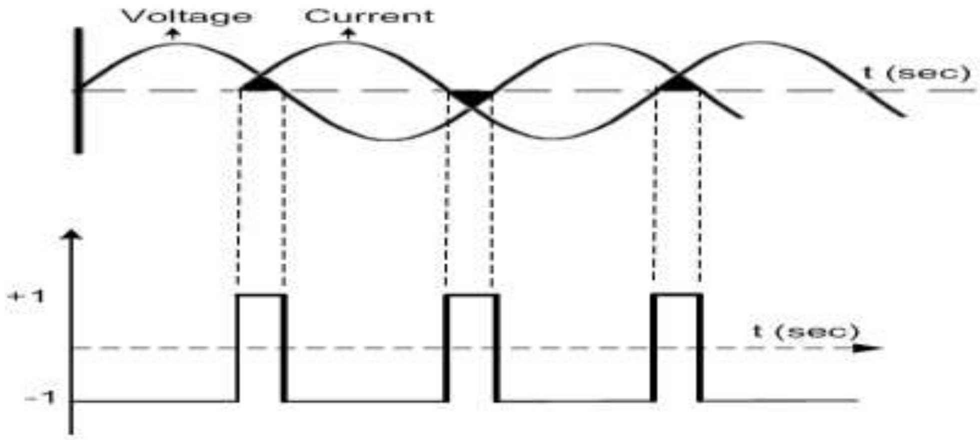

Figure 3b Angle between Voltage and Current Waveforms in the event of Fault environment.

This difference of overlapping interval under normal and reversed power flow conditions will be used to implement the directional element of the relay.

4. MODELING OF REVERSE POWER RELAY

The directional element, delay element and hold elements are plays imperative role in the modeling process of digital reverse power relays as shown in Fig.4.

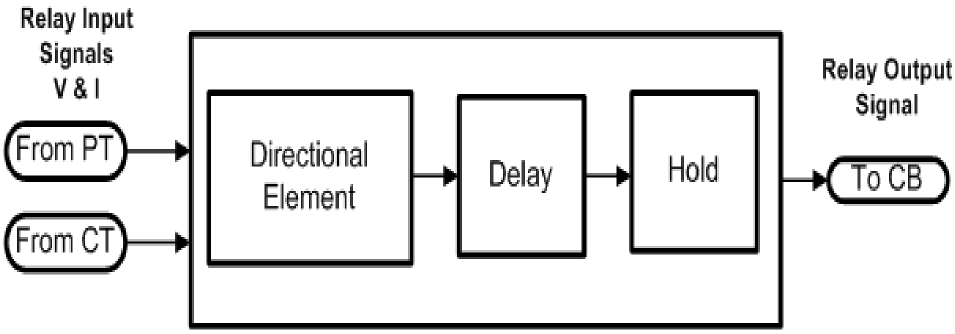

Figure 4 Block Diagram for Implementation of digital Reverse Power Relay

A. Modeling of Directional Element

To acquire perfect square wave with ±1 amplitude two signals from PT & CT have considered. These signals are given to multiplier to give '1' during the overlapping and'-1' for non overlapping interval, output from the multiplier is integrated from 0 to '-L'. Further the upper limit of the integrator in the directional element is set to '0' and analyzed with power flow conditions in the event of pre-fault and during fault conditions. During the healthy condition integrator always '0' and during abnormal condition i.e reverse power flow condition integrator output will fall until it reaches to threshold value. The block diagram for implementing the directional element is shown in Fig. 5 and its implementation on Simulink® is shown in Fig. 6.

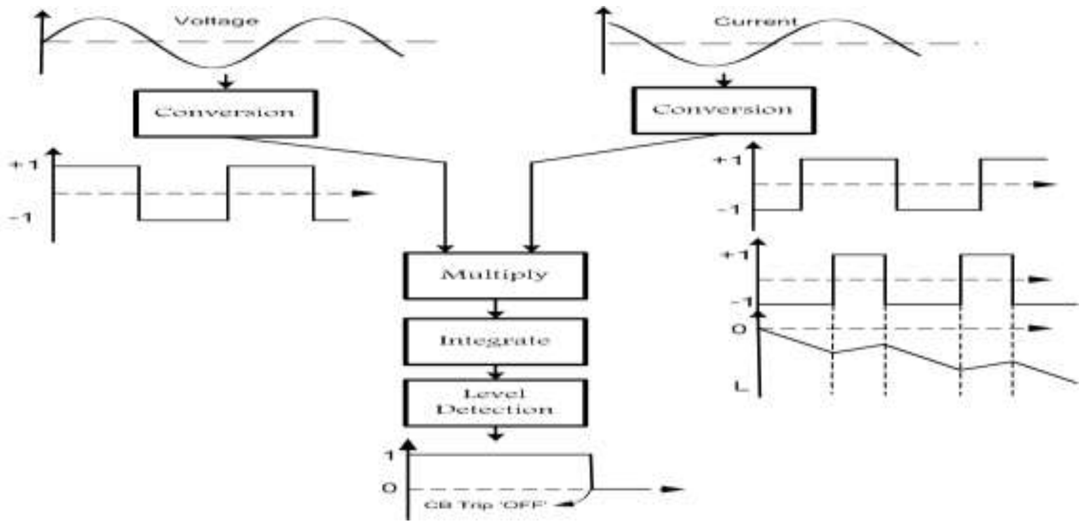

Figure 5 implementation of directional element concept diagram.

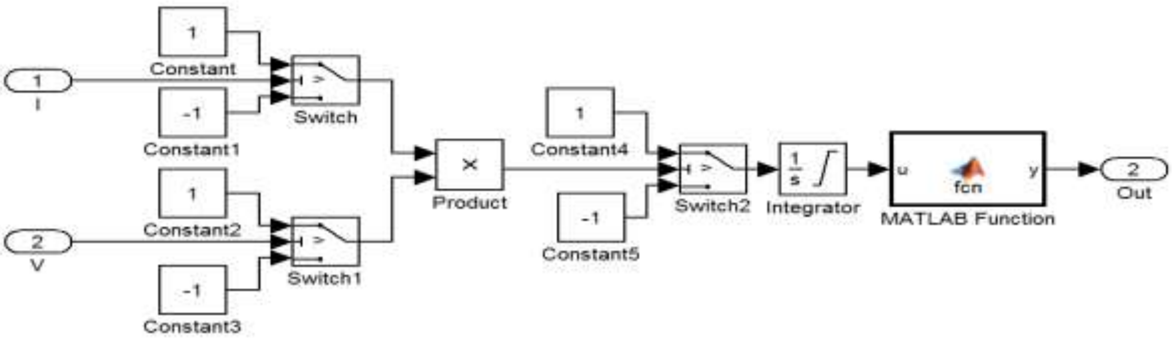

Figure 6 Modeling of Directional Element on SIMULINK®

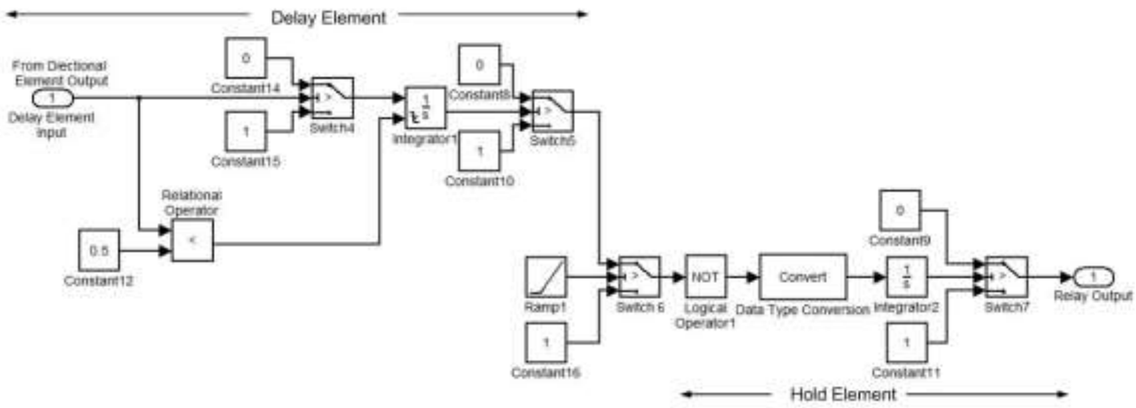

Figure7. Modeling of Delay Element and Hold Element on SIMULINK®

B. Modeling of Delay Element

The utmost essentialities of delay block in the digital relays are to restrict the relay sending false trip signal to the CB in the event of faults. The logic for implementing delay element is represented Fig. 7 (left side).The input to the decision block (SW-4) is taken from the output of a directional element whose '0' output during normal operation and '1' output during faulted condition. Further the output is integrated and compared with threshold value 'T' when the integrator output is less than 'T'. Delay element output value will be '1' indicates normal operation and during abnormal condition the input of a integrator is '1' and after 'T' seconds the output value of a integrator exceeds the 'T' causes to produce '0' from the delay element and it indicates the fault condition.

Further in the event of stable operation condition, input value received by the integrator is '0' (less than 'T') so the delay element output value will be '1'

Finally, during transient or temporary operation condition occurs for less than 'T' seconds, the integrator will be reset to '0' by the relational operator, once the fault disappears.

C. Modeling of Hold Block

To maintain the relay status stable after the relay has tripped hold block is incorporated. This is because, the fault will cease to exist once the CB has opened, it indicates normal operation and persuasive the relay to again send a '1' signal to the CB, causing it to again close.

The integral output which is inverted and integrated taken from delay block is exceeds '0' value, the output of a hold block is changed from '1' to '0'. However here integrator cannot reset therefore once the integral exceeds its threshold of '0' it will never come back to that value and hence the output of the hold block will always be '0' value.

5. RESULTS AND DISCUSSIONS

To facilitate the protection against the bidirectional power flow in distribution system presence of micro turbine DG in the event of faults. The designed and modeled digital relays testing and results are presented as follows. A synchronous machine with 200MVA 11kV specifications are connected with 220kV network through a step up transformer

11/220kV and 5kW micro turbine is integrated as shown in Fig. 6.1. The details of the system are given in appendix. The relay is tested under diverse scenarios. The test conditions, results and discussions are given below.

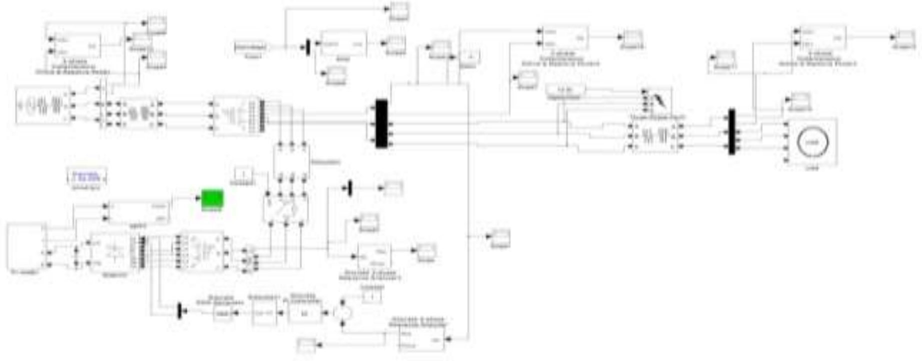

Figure 6.1 Reverse power relay interfaced to distribution system presence of microturbine DG.

A. Case 1:

To illustrate the performance of digital relays in bidirectional power flows detection to protect the power distribution system presence of micro turbine DG in the event of fault.

As a first instant the mechanical input to the generator changes from 0.2pu to 0.8pu at 20 sec due to inception of fault. The mechanical power input/ electrical output power and status of relay is observed is shown in Figure 6.2 (a&b)

In this case, relay does not trip, however electrical output power oscillate initially about the equilibrium point.

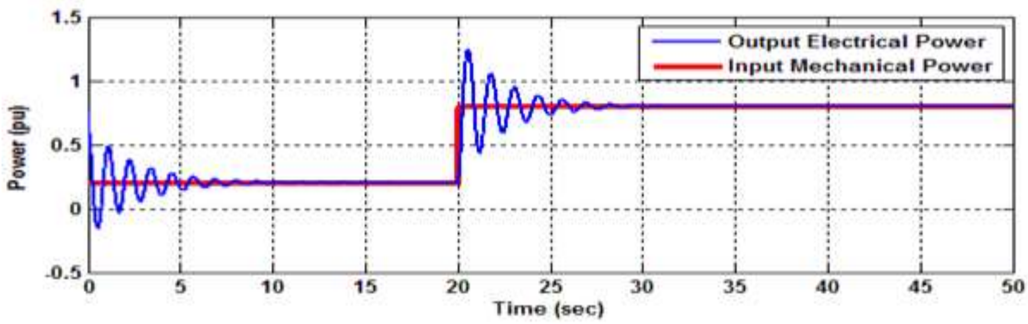

Figure 6.2 (a) Input/output Power of a relay.

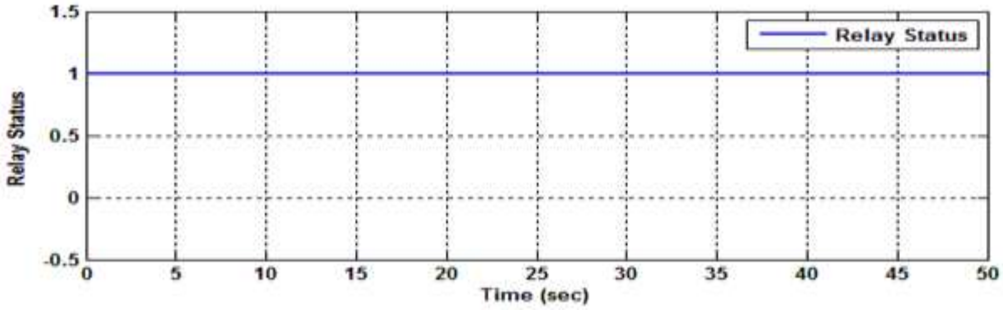

Figure 6.2 (b). Status of Relay.

B. Case 2:

In second case, inception of fault presence of micro turbine DG enforces to change the mechanical input to the generator from 0.5pu to 0.1pu at 90 sec. The mechanical input/electrical output power and status of relay observed, shown in Figure 6.3 (a) & 6.3 (b)

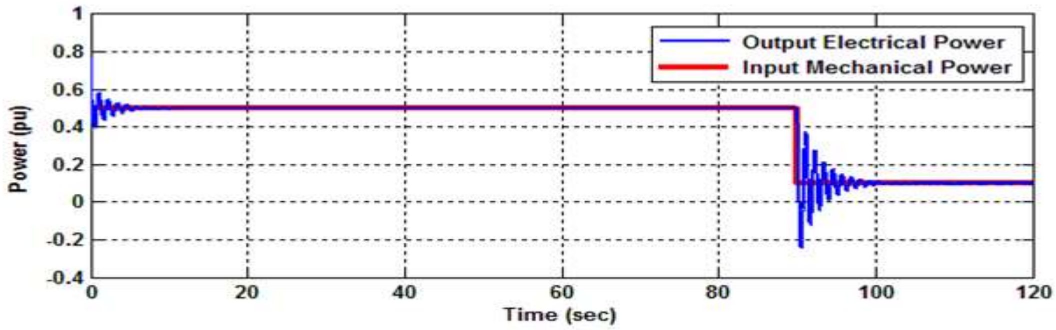

Figure 6.3 (a) Input/output Power of a relay.

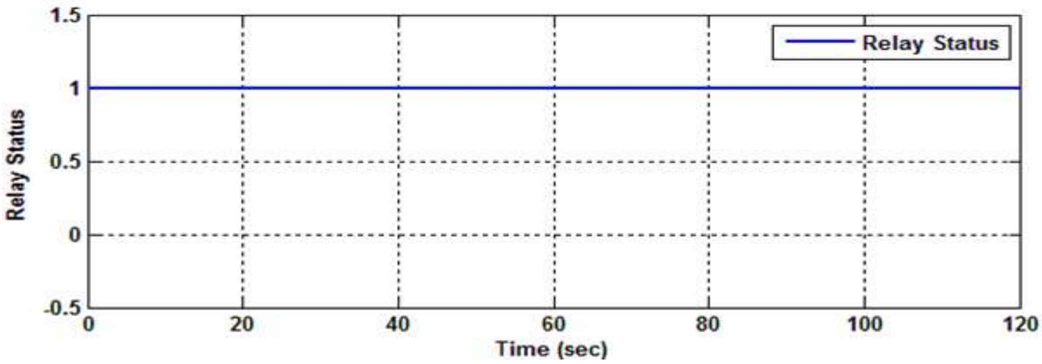

Figure 6.3 (b).Status of relay.

C. Case 3:

In this case, presence of micro turbine DG in the event of fault, the mechanical input to the generator changes from 0.5pu to -0.1pu at 90 sec. The mechanical power input/ electrical power output and status of relay is observed is shown in Figures 6.4 (a) & 6.4 (b).

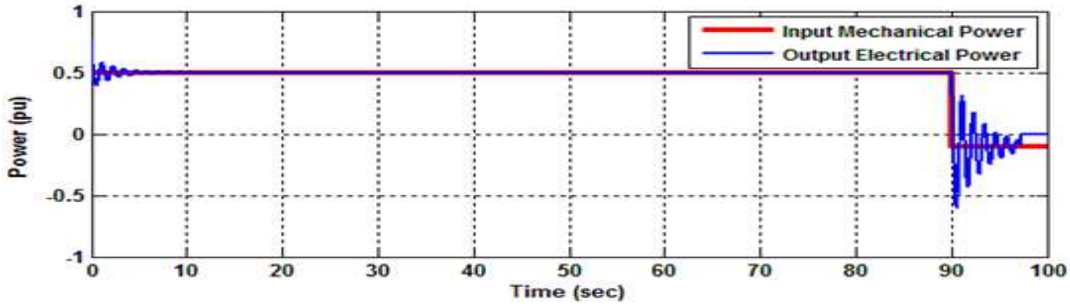

Figure 6.4 (a) Input/output Power of a relay

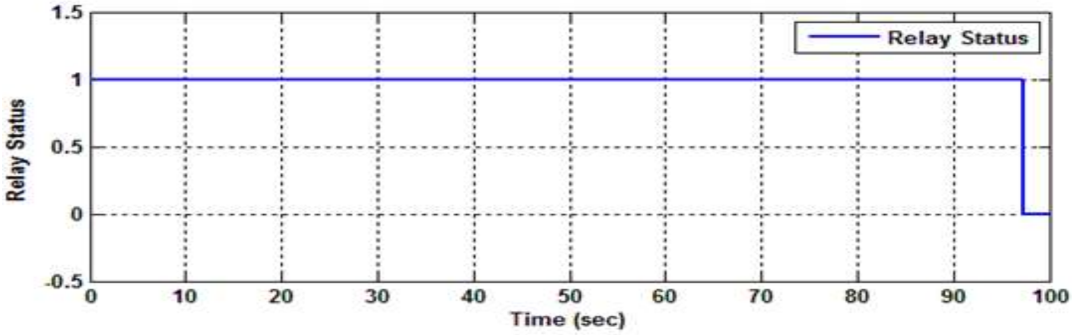

Figure 6.4 (b) Status of relay.

D. Case 4:

A collective case to show the performance of the reverse power relay under different conditions presented in case 4. Numerous times mechanical power changes from 0 to 140 sec. From Figure 6.5(a) & 6.5 (b) it could be observed that the system operates safely during all mechanical transients at the instant mechanical power loss occurred and safely isolated the generator at 107sec

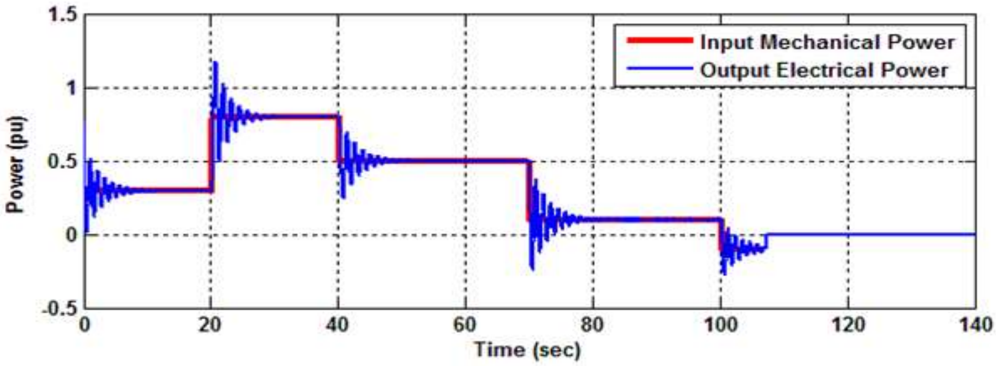

Figure 6.5 (a) Relay Input/output Powers

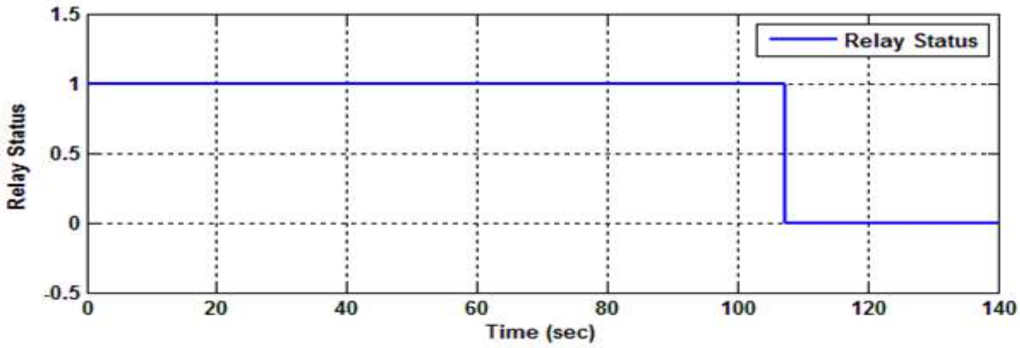

Figure 6.5 (b) Status of relay.

6. CONCLUSIONS

To facilitate the reliable, fast operation and compact size in relays used in bidirectional power detection process, in this paper a novel methodology have introduced to design and model the digital relays in MATLAB/SIMULINK platform. The detection of bidirectional flow in the distribution system with nonlinear load, presence of microturbine DG in the event of system faults has presented. The digitization process is discussed and demonstrated with relevant examples as case studies. the proposed digital relays are brings the effective and efficient bidirectional power detection in power distribution system presence of distributed generators.

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