Modeling and simulation of Differential Protection Relay Based on MATLAB Simulation

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ABSTRACT

In today's demanding business environment, modeling the power system has become necessary in order for utilities to make the right decision when it embarks on any form of asset expansion. Modeling allows the proposed system to be checked for any potential problems, such as mal-operation and incompatibility. The Siemens 7UT6 differential protection relay is used for power transformer differential protection and is capable of protecting transformers of any vector group. This paper covers the steps of modeling the 7UT6 relay and the application of the modeled relay in testing a protection system. A demonstration tripping of vector group D11 will be shown and the fault currents discussed. Graphs showing the phase voltages and currents will be inspected.

Keywords: MatLab Simulation, MatLab Modeling, Simulink Simulation, Power System Protection, Differential Protection Relay.

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1. INTRODUCTION

Utilities are responsible for the generation, transmission, and distribution of electricity to customers. Part of this responsibility is ensuring a safe but yet reliable power supply to customers. For the purpose of safety and protecting transmission and distribution networks from faults, utilities worldwide have sophisticated protective equipment installed on their power system equipment. Collectively, these are known as secondary equipment and include the current transformer (CT), voltage transformer (VT), and protection relays.

The function of protective relaying is to cause the prompt removal from service of any element of a power system when it suffers a short circuit, or when it starts to operate in any abnormal manner that might cause damage or otherwise interfere with the effective operation of the rest of the system. The relaying equipment is aided in this task by circuit breakers that are capable of disconnecting the faulty element when they are called upon to do so by the relaying equipment [i].

Circuit breakers are generally located so that each generator, transformer, bus, transmission line, etc., can be completely disconnected from the rest of the system. These circuit breakers must have sufficient capacity so that they can carry momentarily the maximum short-circuit current that can flow through them, and then interrupt this current; they must also withstand closing in on such a short circuit and then interrupting it according to certain prescribed standards [ii].

In the early days of the electricity supply industry (ESI), electromechanical relays were used. Later, these were replaced by the static relay and then the digital relay. Today, most relays used by the ESI are numerical relays. Numerical relays are microprocessor based and have software to perform the necessary calculations and logic functions of the relay.

There are various types of relays, the main types being the overcurrent relay, distance relay, and differential relay. The differential relay plays an important role in the protection of generator windings, busbars, and transformers. This paper will concentrate specifically on the Siemens 7UT6 Differential Protection Relay.

2. BACKGROUND OF DIFFERENTIAL RELAYS

Differential protection relies on the Kirchoff principle that states that the sum of currents entering a node equals the sum of currents leaving a node. Applied to differential protection, it means that the sum of currents entering a bus equals the sum of those leaving. If the sum of these currents (for a given circuit) is not zero, then it must be due to a short circuit caused either by an earth fault or a phase-to-phase fault.

Differential relays take a variety of forms, depending on the equipment they protect. The definition of such a relay is "one that operates when the vector difference of two or more similar electrical quantities exceeds a predetermined amount" [iii].

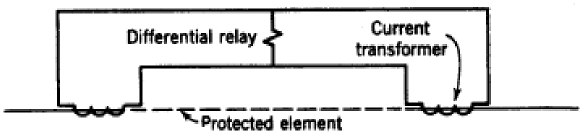


Fig 1: A simple differential-relay application [3]

Figure 1 illustrates the implementation of a simple differential protection application. The dashed portion of the line indicates the protected zone. CTs are installed at either end of the segment and the secondary windings of the CTs are interconnected with a differential relay in parallel.

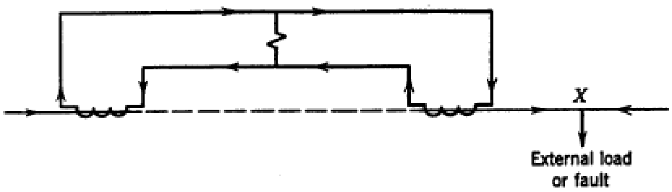


Fig 2: Conditions for an external load or fault

If there is current flow through the line to a load or external fault at X the differential protection should not trip. Provided that the 2 CTs are of the same ratio and properly connected, the secondary currents of the CTs should only circulate as shown by the arrows in Figure 2. Therefore, no current should flow through the differential relay.

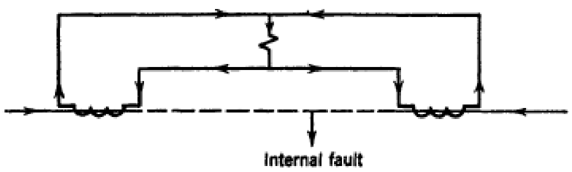


Fig 3: Conditions for an internal fault

Figure 3 illustrates the occurrence of an internal fault. In this case, the sum of currents entering the protected segment does not equal the currents leaving. This results in current flowing through the differential relay, which then initiates a trip.

3. VECTOR GROUP COMPENSATION IN DIFFERENTIAL PROTECTION IN TRANSFORMERS

The main concept of a differential transformer is the difference in current after vector compensation must be as small as possible in order to avoid a trip during normal operation. Usually the scheme would include [iv]:

a) The differential protection relay itself.
b) The Current transformers on both primary and secondary windings.
c) An interposing transformer to compensate difference in vector and current.

This paper will investigate the use of a relay that will eliminate the use of item (c) above. The significance of not having an interposing current transformer is large because the vector group compensation for primary and secondary windings can be done without changing the interposing current transformer.

4. ELIMINATION OF INTERPOSING CURRENT TRANSFORMER IN DIFFERENTIAL PROTECTION SCHEME FOR TRANSFORMERS

Rather than using an interposing current transformer to do all the vector compensation, it is more efficient if the compensation calculations be done in the relay itself. In order to do this, the vector compensation matrix will be needed.
The matrix for this compensation is shown below:

$$A=(2/3)*[\cos(k*30^o),\cos((k+4)*30^o),\cos((k-4)*30^o)\\ \cos((k-4)*30^o),\cos((k)*30^o),\cos((k+4)*30^o)\\ \cos((k+4)*30^o),\cos((k-4)*30^o),\cos((k)*30^o)] \qquad \text{Equation 1.1}$$

Where k represents that secondary winding vector group. This number is represented by the clock convention just like the windings on the transformer windings. For instance, a Yd11 connection on the transformer would represent that the secondary winding is connected in delta and the vector group is leading by 30^o. Therefore if we plug 11 in the matrix above and multiply the matrix that is produced with the readings of current transformers on the transformers secondary winding, the product will be in phase with the readings obtained from the current transformer on the primary side. This is what we mean by vector compensation.

In using the vector compensation method, the relay must exclude the zero sequence components that exist for grounded windings. The presence of zero sequence components can cause mal operation of the relay. The elimination of zero sequence components can be done by introducing another matrix that will eliminate the zero sequence readings on the differential relay. The zero sequence elimination matrix also known as the I_o elimination matrix is shown below:

$$B=(1/3)*[2,-1,-1;\\ -1,2,-1;\\ -1,-1,2] \qquad \text{Equation 1.2}$$

The matrix will remove any zero sequence components that are present in a current transformer reading if the current transformer is connected to ground. In using this matrix, we will multiply the matrix with the current transformer readings that have a ground or neutral connection. The product will be a reading free from zero sequence components.

5. SIMULATION USING MATLAB & SIMULINK

MatLab and Simulink presently do not have a toolbox which helps us in simulating power system protection equipment. Therefore, MatLab scripts must be written in order to model the relays. In our case we are simulating the differential current transformer that includes vector group compensation.

There are four main parts in simulating the differential relay. They include:

1) The setting of the relay by the user
2) The zero sequence elimination of the ground connected transformer current transformer
3) The vector compensation of the secondary winding current transformer output
4) The decision to trip the breakers in an event of a fault.

Relay Settings by relay user.

In this program the user will be asked to input the settings of the relay such as the percentage biases, i_{s1} and i_{s2} setting. For the relay that we design we will also input the vector group of the secondary winding. This is to eliminate the use of interposing current transformers. The relay will also ask the protection engineer if the primary winding is earthed or not. The script used in matlab to set the relay is shown below:

```
k=input('what is the vector group of the delta winding')
r=input('what is the secondary to primary winding ratio of the transformer')
k1=input('please specify the primary percentage bias')
k2=input('please specify the secondary percentage bias')
is1=input('specify the differential current at 0 bias current')
is2=input('specify the bias current when the relay characteristic starts to change')
z=input('is the primary side grounded or not?(0 for no and other number for yes)')
```

The script above is written in the file called hproj3.m. This file is first called in order to set the relay. The first input will define the vector group of the secondary winding. This input must be using the clock convention. The input will be designated as the variable k in workspace. The next input designated as r will ask the user the secondary to primary voltage rating. This will be used by the relay program to equalize the current from the primary and the secondary sides of the transformers assuming the current transformer ratios are the same in the primary and secondary side.

The 3rd and 4th input of the program will ask for the differential biasing of the relay. While the 5th and 6th input is used to input i_{s1} and i_{s2} setting. The last input will ask weather the primary winding is connected to ground or not.

Zero Sequence Elimination for ground connected windings.

The zero sequence elimination block will eliminate the zero sequence component if there is a ground connection on primary winding. In our program, we will ask the user to tell the relay if there is a ground connection in the primary winding. Please refer to section 5.1 to see the input from user concerning the grounding at primary winding. The main script defining the block is shown below. The protocol that is not related to relay operation has been removed for the sake of showing the block operation.

```
b=[1,0,0;0,1,0;0,0,1]
 if z==1
      b=(1/3)*[2,-1,-1;-1,2,-1;-1,-1,2]
elseif z==0
      b=[1,0,0;0,1,0;0,0,1]
 else
      b=(1/3)*[2,-1,-1;-1,2,-1;-1,-1,2]
 end
c=[u(1),u(2),u(3)]
 d=(b*c')'
sys = d;
```

In the script shown above, the block will require input from the workspace named z. This input is given by the user by running program hproj3.m. In this program the block will employ an if else structure. The block will make b equal to an identity matrix in the event the user input that there is no ground connection on the primary winding or put in the zero sequence elimination matrix as b if the user input that the primary winding is connected to ground. The block will then multiply the decided b with the current transformer reading. This will be the output of this block.

a. Vector Compensation Of Secondary Windings

The vector compensation block will only do vector compensation for the readings obtained from the CT readings of the secondary winding. The main script defining the block is shown below. The protocol that is not related to relay operation has been removed for the sake of showing the block operation.

```
a=(2/3)*[cos(k*pi/6),cos((k+4)*pi/6),cos((k-4)*pi/6)
   cos((k-4)*pi/6),cos((k)*pi/6),cos((k+4)*pi/6)
   cos((k+4)*pi/6),cos((k-4)*pi/6),cos((k)*pi/6)]
c=[u(1),u(2),u(3)]
   f=(a*c')'
sys = f;
```

The block will depend on the user input for the value k. After obtaining the matrix a, it will multiply the matrix a with the current transformer input c. The output will be the product of a and c.

b. The Decision block.

Both the input from the zero sequence elimination and vector compensation block will be input to the decision block. The diagram below shows how the blocks are connected together:

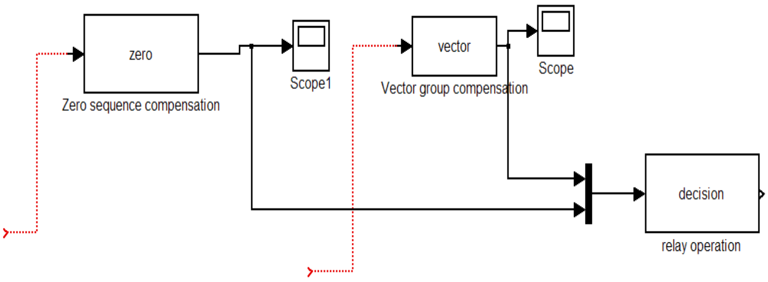


Figure 5.4.1 Relay block diagram.

The main script for the decision block is shown below:

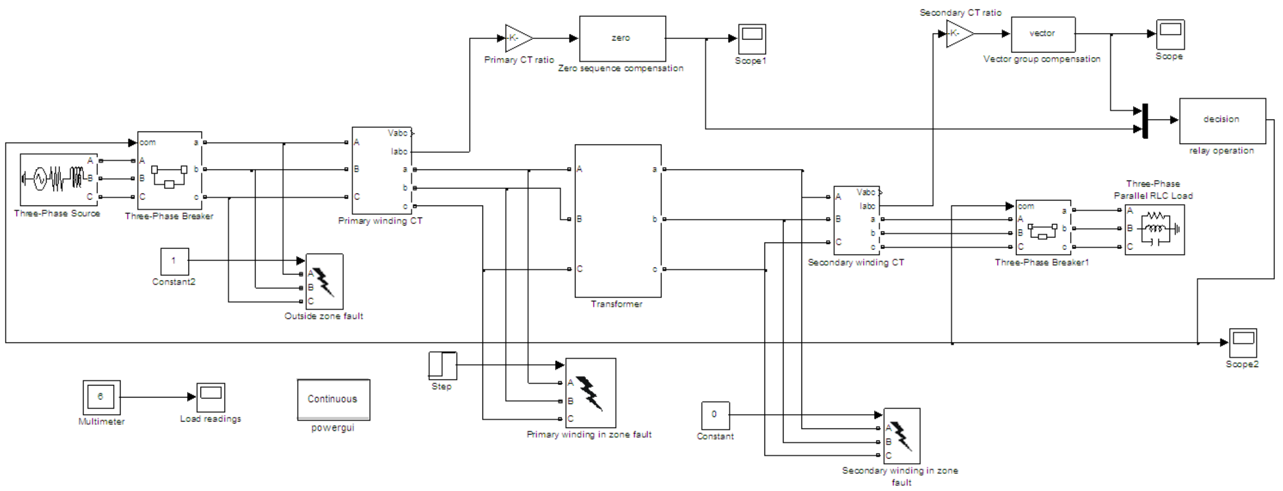
```
function sys = mdlUpdate(t,x,u,r,k1,k2,is1,is2)
c=r*[u(1),u(2),u(3)];
 d=[u(4),u(5),u(6)];
idiff=abs(c-d);
ibias=abs(d+c)/2;
i=1;
if x==1%check for lock out
while i<=3
if ibias(i)<=is2
        if idiff(i)>(k1*ibias(i)+is1)
        x=0;%close breaker if there is a fault.
        break
        else
        x=1;%leave circuit in close circuit if there is balanced situation
        end

  else
        if idiff(i)>(k2*ibias(i)+(k1-k2)*is1)
        x=0;%open circuit breaker if there is unbalanced situation
        break
        else
        x=1;%leave circuit in close circuit if there is balanced situation
        end
end
i=i+1;
end
else
   x=0;%lock out.
end
sys=x;
function sys=mdlOutputs(t,x,u,r,k1,k2,is1,is2)
sys = x;%system output
```

The block output will be an input to the breakers connected to the transformer. An output of 1 from this block will tell the breaker to keep closed and an output of 0 will tell the breaker to open. Therefore this block will need to use the previous condition or state to make the present decision. If the past output is 1 then the block will see if there is a fault. If not then the block will have to output a 0. This condition is called lock out. This is important because the output of this block will be used to operate the relay where the breaker will close if the input is 1 and open if the input is 0. If lock out does not exist, then the relay will not detect a fault when the relay is open and close the breaker again. Without lock out a condition where the relay will open and close rapidly the instant we have a fault will exist.

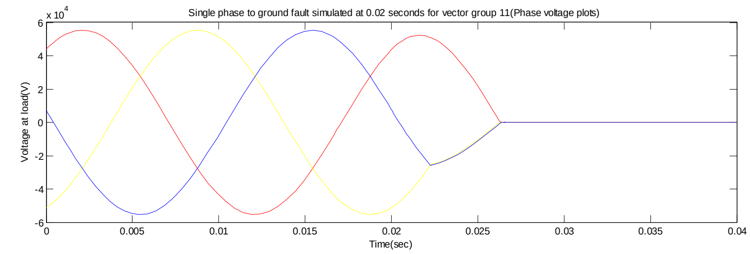
CONCLUSION

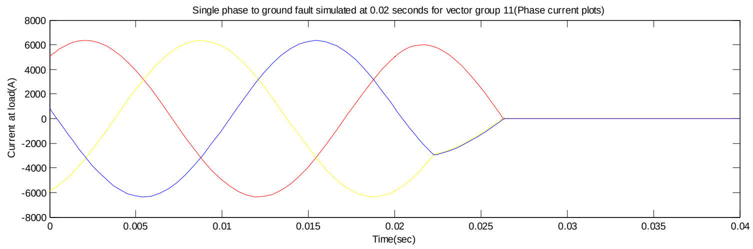
Based on the above results, it is seen that MatLab provides an accurate modeling platform to test and simulate the Siemens 7UT6 Differential Protection Relay.

Appendix I – MatLab Simulink Model

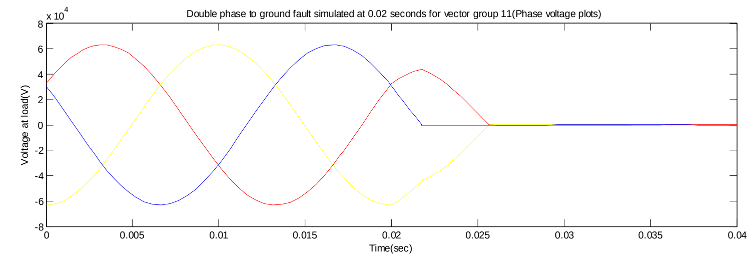


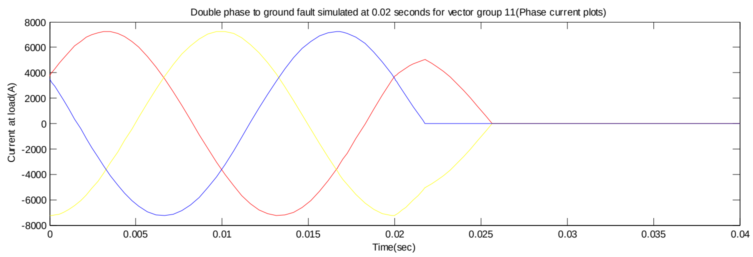
Appendix II – Example fault trippings for D11 Vector Group



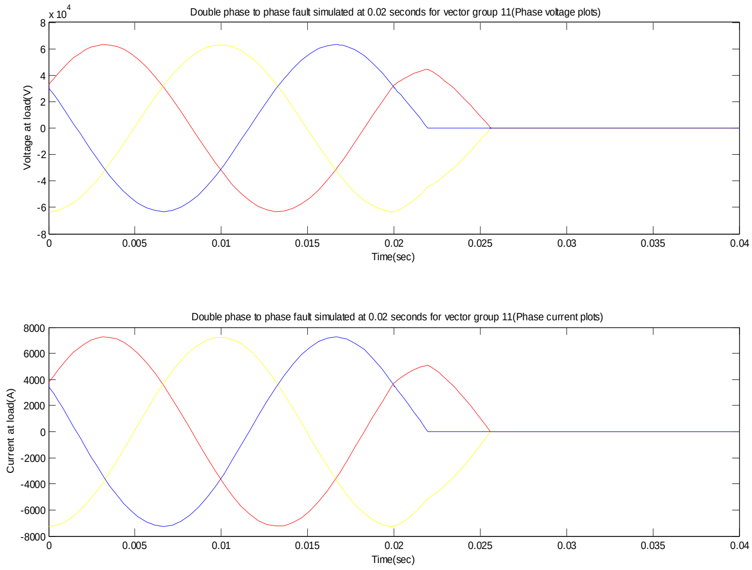


Single phase to ground fault

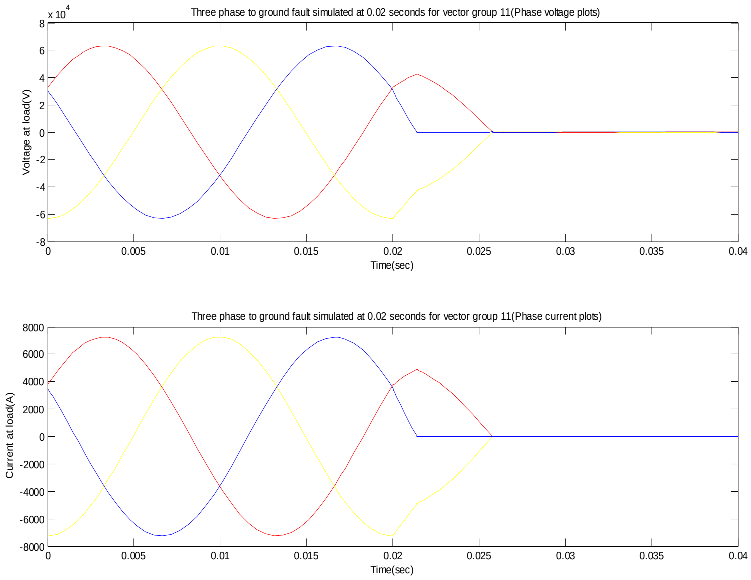




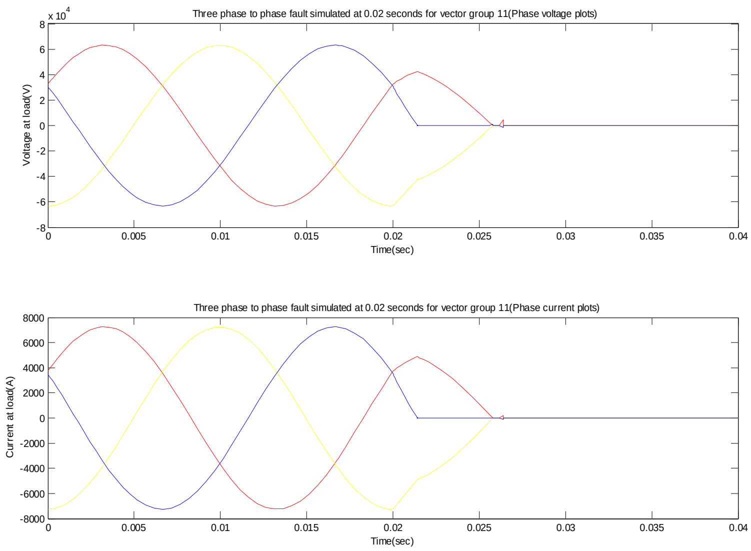
Double phase to ground fault



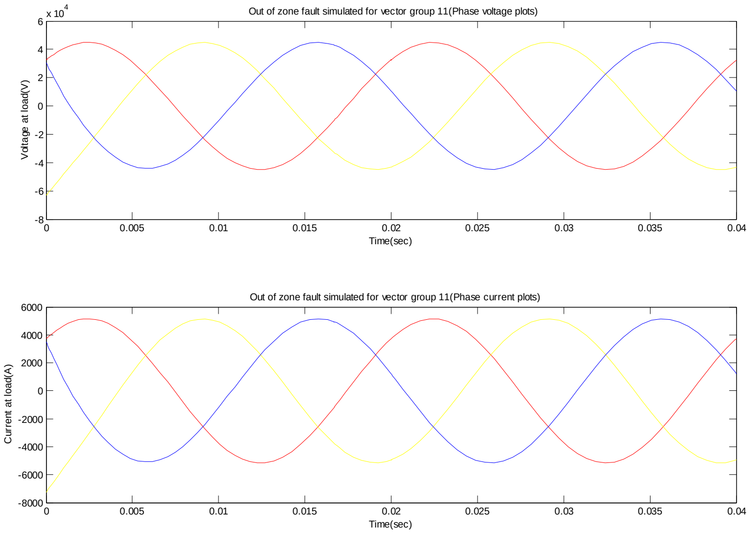
Double phase-to-phase fault



Triple phase bolted fault to ground



Triple phase-to-phase fault



Out of zone fault

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