**Relay pair classification**



When a fault occurs at line k, location h pair relay performance (full, partial and no detection) can be enclosed

In one of the following six types:

Type 1: Complete fault detection in a relay pair q-p (case 1).

Type 2: Complete fault detection in a relay pair i-j (case 2).

Type 3: Partial fault detection in relay j in period 1.

Type 3a: Relay j is stuck due to loss sensitivity in period 1 (case 3)

Type 3b: Relay j is stuck due to current in the opposite direction in period 1 (case 4)

Type 3c: Relay j is stuck due to current in the opposite direction and no sensitivity in period 1 (case 5)

Type 4: Partial fault detection in relay i: Relay i is stuck due to no sensitivity in period 1 (case 6)

Type 5: Partial fault detection in relay i and relay j:

Type 5a: Relay i and j are stuck due to no sensitivity in period 1 (case 7)

Type 5b: Relay i is stuck due to no sensitivity and relay j is stuck due to current in the opposite direction in period 1 (case 8)

Type 5c: Relay i and j are stuck due to no sensitivity and relay j is stuck due to current in the opposite direction in period 1 (case 9)

Type 6: No fault detection at all

Type 6a: Relay p is stuck due to current in the opposite direction in period 1 (case 10)

Type 6b: Relay j is stuck due to current in the opposite direction in period 2 (case 11)

Type 6c: Relay p is stuck due to no sensitivity in period 1 (case 12)

Type 6d: Relay p is stuck due to current in the opposite direction and no sensitivity in period 1 (case 13)

Type 6e: Relay i is stuck due to current in the opposite direction in period 2 (case 14)

Type 6f: Relay j is stuck due to no sensitivity in period 2 (case 15)

**Type 1: Complete fault detection in a relay pair q-p (case 1).**

This happens when fault currents at q and p relays at first period go in the same direction, and

Relays p is sensitive.



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Normal operation is achieved when the following conditions are achieved:

1.- In the first period, fault current Ipkh goes in the same direction than Iqkh if angle difference between fault currents Ipkh and Iqkh is NOT greater than an admissible polarization angle f.

|qpkh – qqkh|> f is NOT true, or |qpkh – qqkh|< f Is true

2.- In the first period, backup relay p is sensitive if fault current magnitude Ipkh is NOT lower than its pick-up current Pp. In this case, the ratio Iqkh / Pq yields a positive b parameter. Therefore, sensitivity is achieved at relay p if:

bpkh < 0 Is NOT true, or bpkh > 0 is true

Notice that relay q is always sensitive at first period.

In case 1 a coordination interval S exists and a primary time Tq can be calculated.

Therefore, the corresponding classification code is:

% Type 1 - Case 1 - Normal Operation qp

for g=1:length(C2(:,1))

if abs(theta(C2(g,1),C2(g,3))-theta(C2(g,2),C2(g,3))) < qmax &...

%period 1: no reverse current relay p

beta(C2(g,1),C2(g,3)) > 0 &...

%period 1: no loss of sensitivity relay p

flag=flag+1;

fl(1)=fl(1)+1;

S(flag)=beta(C2(g,1),C2(g,3))\*D(C2(g,1))-beta(C2(g,2),C2(g,3))\*D(C2(g,2));

Tq(flag)=beta(C2(g,2),C2(g,3))\*D(C2(g,2));

end

**Type 2: Complete fault detection in relay pairs i-j (case 2).**

This happens when fault currents at relays i and j go in the same direction in both periods, and

Relays i and j are both sensitive in both periods.



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Normal operation is achieved when all the following conditions are achieved:

1.- In both periods, fault currents Ijkh, I’jkh go in the same direction of Iikh,Iikh if angle difference between fault currents Ijkh, I’jkh and Iikh,Iikh are NOT greater than an admissible polarization angle f.

|qjkh – qikh|> f Is NOT true, or |qjkh – qikh|< f Is true

|q'jkh – q'ikh|> f Is NOT true, or |q'jkh – q'ikh|< f Is true

2.- In both periods, backup relay j and primary relay I are sensitive if fault current magnitudes Ijkh, I’jkh ,Iikh, I’ikh are NOT lower than its pick-up current Pp. In this case, ratios Ijkh / Pj ,Ijkh / Pj ,Iikh / Pi and I’ikh / Pi yield positive b parameters. Therefore, sensitivity at relays j and i are achieved if:

bjkh < 0 Is NOT true, or bjkh > 0 Is true

bikh < 0 Is NOT true, or bikh > 0 Is true

b'jkh < 0 Is NOT true, or b'jkh > 0 Is true

b'ikh < 0 Is NOT true, or b'ikh > 0 Is true

In this case a coordination interval S exists and a primary time T\*i can be calculated.

Therefore, the corresponding classification code is:

%%---------------------------------------------------------

% Type 2 - Case 2 - Normal Operation ij

for g=1:length(C1(:,1))

if abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) < qmax &... %period 1: no reverse current relay j

abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax &... %period 2: no reverse current relay j

beta(C1(g,1),C1(g,3)) > 0 &...%period 1: no loss of sensitivity relay j

betap(C1(g,1),C1(g,3)) > 0 &...%period 2: no loss of sensitivity relay j

beta(C1(g,2),C1(g,3)) > 0 &...%period 1: no loss of sensitivity relay i

betap(C1(g,2),C1(g,3)) > 0 %period 2: no loss of sensitivity relay i

flag=flag+1;

fl(2)=fl(2)+1;

S(flag)=betap(C1(g,1),C1(g,3))\*D(C1(g,1))-betap(C1(g,2),C1(g,3))\*D(C1(g,2))-gammap(C1(g,4),C1(g,1),C1(g,2),C1(g,3))\*D(C1(g,4));

Tj=beta(C1(g,1),C1(g,3))\*D(C1(g,1));

Ti=beta(C1(g,2),C1(g,3))\*D(C1(g,2));

Tqq=beta(C1(g,4),C1(g,3))\*D(C1(g,4));

Tpj=betap(C1(g,1),C1(g,3))\*D(C1(g,1));

Tpi=betap(C1(g,2),C1(g,3))\*D(C1(g,2));

Tix(flag)=Tqq+Tpi\*(1-Tqq/Ti);

Tjx(flag)=Tqq+Tpj\*(1-Tqq/Tj);

end

end% End of Type 2 - Case 2

**Type 3: Partial fault detection in relay j in period 1.**

**Type 3a: Relay j is stuck due to loss sensitivity in period 1 (case 3)**

This happens when fault currents at relays i and j go in the same direction in both periods, and

Relays i and j are both sensitive in period 2.

Relay i is sensitive in period 1 and relay j is NOT sensitive at period 1.

Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Partial operation is achieved when all the following conditions are achieved:

1.- In both periods, fault currents Ijkh, I’jkh go in the same direction of Iikh,Iikh if angle difference between fault currents Ijkh, I’jkh and Iikh,Iikh are NOT greater than an admissible polarization angle f.

|qjkh – qikh|> f Is NOT true, or |qjkh – qikh|< f Is true

|q'jkh – q'ikh|> f Is NOT true, or |q'jkh – q'ikh|< f Is true

2.- If

bjkh < 0 Is true, or bjkh > 0 Is NOT true and, relay j is NOT sensitive ate period 1

bikh < 0 Is NOT true, or bikh > 0 is true and, relay i is sensitive at period 1

b'jkh < 0 Is NOT true, or b'jkh > 0 Is true and, relay j is sensitive at period 2

b'ikh < 0 Is NOT true, or b'ikh > 0 Is true and, relay i is sensitive at period 2

In this case a coordination interval S exists and a primary time T\*i can be calculated.

Therefore, the corresponding classification code is:

%%---------------------------------------------------------

% Type 3a - Case 3

for g=1:length(C1(:,1))

if abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) < qmax &... %period 1: no reverse current relay j

abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax &... %period 2: no reverse current relay j

beta(C1(g,1),C1(g,3)) < 0 &...%period 1: yes loss of sensitivity relay j

betap(C1(g,1),C1(g,3)) > 0 &...%period 2: no loss of sensitivity relay j

beta(C1(g,2),C1(g,3)) > 0 &...%period 1: no loss of sensitivity relay i

betap(C1(g,2),C1(g,3)) > 0%period 2: no loss of sensitivity relay i

flag=flag+1;

fl(3)=fl(3)+1;

S(flag)=betap(C1(g,1),C1(g,3))\*D(C1(g,1))-betap(C1(g,2),C1(g,3))\*D(C1(g,2))-gammapp(C1(g,4),C1(g,1),C1(g,2),C1(g,3))\*D(C1(g,4));

Tj=beta(C1(g,1),C1(g,3))\*D(C1(g,1));

Ti=beta(C1(g,2),C1(g,3))\*D(C1(g,2));

Tqq=beta(C1(g,4),C1(g,3))\*D(C1(g,4));

Tpj=betap(C1(g,1),C1(g,3))\*D(C1(g,1));

Tpi=betap(C1(g,2),C1(g,3))\*D(C1(g,2));

Tix(flag)=Tqq+Tpi\*(1-Tqq/Ti);

Tjx(flag)=Tix(flag)+S(flag);

end

end% End Type 3a - Case 3

**Type 3: Partial fault detection in relay j in period 1.**

**Type 3b: Relay j is stuck due to current in the opposite direction in period 1 (case 4)**

This happens when fault currents at relays i and j go in the opposite direction in the first period, and Relays i and j are both sensitive in both periods.



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Partial operation is achieved when all the following conditions are achieved:

1.- In first period, fault currents Ijkh and Iikh go in the opposite direction if angle difference between fault currents Ijkh and Iikh is greater than an admissible polarization angle f.

|qjkh – qikh|> f Is true, or |qjkh – qikh|< f Is NOT true

2.- In second periods, fault currents I’ikh and I’jkh go in the same direction if angle difference between fault currents I’jkh and Iikh is NOT greater than an admissible polarization angle f.

|q'jkh – q'ikh|> f Is NOT true, or |q'jkh – q'ikh|< f Is true

3.- In both periods, backup relay j and primary relay I are sensitive if fault current magnitudes Ijkh, I’jkh ,Ijkh, I’jkh are NOT lower than its pick-up current Pp. In this case, ratios Ijkh / Pj ,Ijkh / Pj ,Iikh / Pi and I’ikh / Pi yield positive b parameters. Therefore, sensitivity at relays j and i are achieved if:

bjkh < 0 Is NOT true, or bjkh > 0 Is true

bikh < 0 Is NOT true, or bikh > 0 Is true

b'jkh < 0 Is NOT true, or b'jkh > 0 Is true

b'ikh < 0 Is NOT true, or b'ikh > 0 Is true

In this case a coordination interval S exists and a primary time T\*i can be calculated.

Therefore, the corresponding classification code is:

% Type 3b - Case 4

for g=1:length(C1(:,1))

if abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) > qmax &... %period 1: yes reverse current relay j

abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax &... %period 2: no reverse current relay j

beta(C1(g,1),C1(g,3)) > 0 &...%period 1: no loss of sensitivity relay j

betap(C1(g,1),C1(g,3)) > 0 &...%period 2: no loss of sensitivity relay j

beta(C1(g,2),C1(g,3)) > 0 &...%period 1: no loss of sensitivity relay i

betap(C1(g,2),C1(g,3)) > 0 %period 2: no loss of sensitivity relay i

flag=flag+1;

fl(4)=fl(4)+1;

S(flag)=betap(C1(g,1),C1(g,3))\*D(C1(g,1))-betap(C1(g,2),C1(g,3))\*D(C1(g,2))-gammapp(C1(g,4),C1(g,1),C1(g,2),C1(g,3))\*D(C1(g,4));

Tj=beta(C1(g,1),C1(g,3))\*D(C1(g,1));

Ti=beta(C1(g,2),C1(g,3))\*D(C1(g,2));

Tqq=beta(C1(g,4),C1(g,3))\*D(C1(g,4));

Tpj=betap(C1(g,1),C1(g,3))\*D(C1(g,1));

Tpi=betap(C1(g,2),C1(g,3))\*D(C1(g,2));

Tix(flag)=Tqq+Tpi\*(1-Tqq/Ti);

Tjx(flag)=Tix(flag)+S(flag);

End

**Type 3: Partial fault detection in relay j in period 1.**

**Type 3c: Relay j is stuck due to current in the opposite direction and no sensitivity in period 1 (case 5)**

This happens when fault currents at relays i and j go in the opposite direction in the first period, relay j is sensitive in the first period but no sensitive at second one, and relay i is sensitive in both periods.



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Partial operation is achieved when all the following conditions are achieved:

1.- In first period, fault currents Ijkh and Iikh go in the opposite direction if angle difference between fault currents Ijkh and Iikh is greater than an admissible polarization angle f.

|qjkh – qikh|> f Is true, or |qjkh – qikh|< f Is NOT true

2.- In second periods, fault currents I’ikh and I’jkh go in the same direction if angle difference between fault currents I’jkh and Iikh is NOT greater than an admissible polarization angle f.

|q'jkh – q'ikh|> f Is NOT true, or |q'jkh – q'ikh|< f Is true

3.- if

bjkh < 0 Is true, or bjkh > 0 Is NOT true and, relay j is NOT sensitive at period 1

bikh < 0 Is NOT true, or bikh > 0 is true and, relay i is sensitive at period 1

b'jkh < 0 Is NOT true, or b'jkh > 0 Is true and, relay j is sensitive at period 2

b'ikh < 0 Is NOT true, or b'ikh > 0 Is true and, relay i is sensitive at period 2

In this case a coordination interval S exists and a primary time T\*i can be calculated.

Therefore, the corresponding classification code is:

%%---------------------------------------------------------

% Type 3c - Case 5

for g=1:length(C1(:,1))

if abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) > qmax &...

%period 1: yes reverse current relay j

abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax &...

%period 2: no reverse current relay j

beta(C1(g,1),C1(g,3)) < 0 &...%period 1: yes loss of sensitivity relay j

betap(C1(g,1),C1(g,3)) > 0 &...%period 2: no loss of sensitivity relay j

beta(C1(g,2),C1(g,3)) > 0 &...%period 1: no loss of sensitivity relay i

betap(C1(g,2),C1(g,3)) > 0 %period 2: no loss of sensitivity relay iflag=flag+1;

fl(5)=fl(5)+1;

S(flag)=betap(C1(g,1),C1(g,3))\*D(C1(g,1))-betap(C1(g,2),C1(g,3))\*D(C1(g,2))-gammapp(C1(g,4),C1(g,1),C1(g,2),C1(g,3))\*D(C1(g,4));

Tj=beta(C1(g,1),C1(g,3))\*D(C1(g,1));

Ti=beta(C1(g,2),C1(g,3))\*D(C1(g,2));

Tqq=beta(C1(g,4),C1(g,3))\*D(C1(g,4));

Tpj=betap(C1(g,1),C1(g,3))\*D(C1(g,1));

Tpi=betap(C1(g,2),C1(g,3))\*D(C1(g,2));

Tix(flag)=Tqq+Tpi\*(1-Tqq/Ti);

Tjx(flag)=Tix(flag)+S(flag);

end

end

**Type 4: Partial fault detection in relay pairs i: Relay i is stuck due to no sensitivity in period 1 (case 6)**

This happens when fault currents at relays i and j go in the same direction in both periods, and

Relays i and j are both sensitive in period 2.

Relay j is sensitive in period 1 but relay i is NOT sensitive at period 1.

Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Partial operation is achieved when all the following conditions are achieved:

1.- In both periods, fault currents Ijkh, I’jkh go in the same direction of Iikh,Iikh if angle difference between fault currents Ijkh, I’jkh and Iikh,Iikh are NOT greater than an admissible polarization angle f.

|qjkh – qikh|> f Is NOT true, or |qjkh – qikh|< f Is true

|q'jkh – q'ikh|> f Is NOT true, or |q'jkh – q'ikh|< f Is true

2.- If

bjkh < 0 Is NOT true, or bjkh > 0 is true and, relay j is sensitive at period 1

bikh < 0 Is true, or bikh > 0 Is NOT true and, relay i is NOT sensitive at period 1

b'jkh < 0 Is NOT true, or b'jkh > 0 Is true and, relay j is sensitive at period 2

b'ikh < 0 Is NOT true, or b'ikh > 0 Is true and, relay i is sensitive at period 2

In this case a coordination interval S exists and a primary time T\*i can be calculated.

a coordination interval S exists and a primary time T\*i can be calculated.

Therefore, the corresponding classification code is:

%%---------------------------------------------------------

% Type 4 - Case 6

for g=1:length(C1(:,1))

if abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) < qmax &... %period 1: no reverse current relay j

abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax &... %period 2: no reverse current relay j

beta(C1(g,1),C1(g,3)) > 0 &...%period 1: no loss of sensitivity relay j

betap(C1(g,1),C1(g,3)) > 0 &...%period 2: no loss of sensitivity relay j

beta(C1(g,2),C1(g,3)) < 0 &...%period 1: yes loss of sensitivity relay i

betap(C1(g,2),C1(g,3)) >0 %period 2: no loss of sensitivity relay iif abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) < qmax & abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax & beta(C1(g,1),C1(g,3)) > 0 & betap(C1(g,1),C1(g,3)) > 0 & beta(C1(g,2),C1(g,3)) < 0 & betap(C1(g,2),C1(g,3)) > 0 & beta(C1(g,4),C1(g,3))\*D(C1(g,4))

flag=flag+1;

fl(6)=fl(6)+1;

S(flag)=betap(C1(g,1),C1(g,3))\*D(C1(g,1))-betap(C1(g,2),C1(g,3))\*D(C1(g,2))-gammappp(C1(g,4),C1(g,1),C1(g,2),C1(g,3))\*D(C1(g,4));

Tj=beta(C1(g,1),C1(g,3))\*D(C1(g,1));

Ti=beta(C1(g,2),C1(g,3))\*D(C1(g,2));

Tqq=beta(C1(g,4),C1(g,3))\*D(C1(g,4));

Tpj=betap(C1(g,1),C1(g,3))\*D(C1(g,1));

Tpi=betap(C1(g,2),C1(g,3))\*D(C1(g,2));

Tjx(flag)=Tqq+Tpj\*(1-Tqq/Tj);

Tix(flag)=Tjx(flag)-S(flag);

end

end

% End Type 4 - Case 6

**Type 5: Partial fault detection in relay i and relay j:**

**Type 5a: Relay i and j are stuck due to no sensitivity in period 1 (case 7)**

This happens when fault currents at relays i and j go in the same direction in both periods, and

Relays I and j are both sensitive in period 2, and relays i and j are both NOT sensitive at period 1.

Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Partial operation is achieved when all the following conditions are achieved:

1.- In both periods, fault currents Ijkh, I’jkh go in the same direction of Iikh,Iikh if angle difference between fault currents Ijkh, I’jkh and Iikh,Iikh are NOT greater than an admissible polarization angle f.

|qjkh – qikh|> f Is NOT true, or |qjkh – qikh|< f Is true

|q'jkh – q'ikh|> f Is NOT true, or |q'jkh – q'ikh|< f Is true

2.- If

bjkh < 0 Is true, or bjkh > 0 is NOT true and, relay j is NOT sensitive ate period 1

bikh < 0 Is true, or bikh > 0 is NOT true and, relay i is NOT sensitive at period 1

b'jkh < 0 Is NOT true, or b'jkh > 0 Is true and, relay j is sensitive at period 2

b'ikh < 0 Is NOT true, or b'ikh > 0 Is true and, relay i is sensitive at period 2

In this case a coordination interval S exists and a primary time T\*i can be calculated.

Therefore, the corresponding classification code is:

%%---------------------------------------------------------

% Type 5a - Case 7

for g=1:length(C1(:,1))

if abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) < qmax &... %period 1: no reverse current relay j

abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax &... %period 2: no reverse current relay j

beta(C1(g,1),C1(g,3)) < 0 &...%period 1: yes loss of sensitivity relay j

betap(C1(g,1),C1(g,3)) > 0 &...%period 2: no loss of sensitivity relay j

beta(C1(g,2),C1(g,3)) < 0 &...%period 1: yes loss of sensitivity relay i

betap(C1(g,2),C1(g,3)) > 0 %period 2: no loss of sensitivity relay i

fl(7)=fl(7)+1;

S(flag)=betap(C1(g,1),C1(g,3))\*D(C1(g,1))-betap(C1(g,2),C1(g,3))\*D(C1(g,2))-0\*gammappp(C1(g,4),C1(g,1),C1(g,2),C1(g,3))\*D(C1(g,4));

Tj=beta(C1(g,1),C1(g,3))\*D(C1(g,1));

Ti=beta(C1(g,2),C1(g,3))\*D(C1(g,2));

Tqq=beta(C1(g,4),C1(g,3))\*D(C1(g,4));

Tpj=betap(C1(g,1),C1(g,3))\*D(C1(g,1));

Tpi=betap(C1(g,2),C1(g,3))\*D(C1(g,2));

Tix(flag)=Tpi;

Tjx(flag)=Tpj;

end

end

% End Type 5a - Case 7

**Type 5: Partial fault detection in relay i and relay j:**

**Type 5b: Relay i is stuck due to no sensitivity and relay j is stuck due to current in the opposite direction in period 1 (case 8)**

This happens when fault currents at relays i and j go in the opposite direction in the first period, relay i is not sensitive at first period and, relay j is sensitive in both periods.



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Partial operation is achieved when all the following conditions are achieved:

1.- In first period, fault currents Ijkh and Iikh go in the opposite direction if angle difference between fault currents Ijkh and Iikh is greater than an admissible polarization angle f.

|qjkh – qikh|> f Is true, or |qjkh – qikh|< f Is NOT true

2.- In second periods, fault currents I’ikh and I’jkh go in the same direction if angle difference between fault currents I’jkh and Iikh is NOT greater than an admissible polarization angle f.

|q'jkh – q'ikh|> f Is NOT true, or |q'jkh – q'ikh|< f Is true

3.- If

bjkh < 0 Is NOT true, or bjkh > 0 is true and, relay j is sensitive at period 1

bikh < 0 Is true, or bikh > 0 Is NOT true and, relay i is NOT sensitive at period 1

b'jkh < 0 Is NOT true, or b'jkh > 0 Is true and, relay j is sensitive at period 2

b'ikh < 0 Is NOT true, or b'ikh > 0 Is true and, relay i is sensitive at period 2

In this case a coordination interval S exists and a primary time T\*i can be calculated.

Therefore, the corresponding classification code is:

%%---------------------------------------------------------

% Type 5b - Case 8

for g=1:length(C1(:,1))

if abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) > qmax &... %period 1: yes reverse current relay j

abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax &... %period 2: no reverse current relay j

beta(C1(g,1),C1(g,3)) > 0 &...%period 1: no loss of sensitivity relay j

betap(C1(g,1),C1(g,3)) > 0 &...%period 2: no loss of sensitivity relay j

beta(C1(g,2),C1(g,3)) < 0 &...%period 1: yes loss of sensitivity relay i

betap(C1(g,2),C1(g,3)) >0 %period 2: no loss of sensitivity relay iif abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) > qmax & abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax & beta(C1(g,1),C1(g,3)) > 0 & betap(C1(g,1),C1(g,3)) > 0 & beta(C1(g,2),C1(g,3)) < 0 & betap(C1(g,2),C1(g,3)) > 0 & beta(C1(g,4),C1(g,3))\*D(C1(g,4))

flag=flag+1;

fl(8)=fl(8)+1;

S(flag)=betap(C1(g,1),C1(g,3))\*D(C1(g,1))-betap(C1(g,2),C1(g,3))\*D(C1(g,2))-0\*gammappp(C1(g,4),C1(g,1),C1(g,2),C1(g,3))\*D(C1(g,4));

Tj=beta(C1(g,1),C1(g,3))\*D(C1(g,1));

Ti=beta(C1(g,2),C1(g,3))\*D(C1(g,2));

Tqq=beta(C1(g,4),C1(g,3))\*D(C1(g,4));

Tpj=betap(C1(g,1),C1(g,3))\*D(C1(g,1));

Tpi=betap(C1(g,2),C1(g,3))\*D(C1(g,2));

Tix(flag)=Tpi;

Tjx(flag)=Tpj;

end

end

% End Type 5b - Case 8

**Type 5: Partial fault detection in relay i and relay j:**

**Type 5c: Relay i and j are stuck due to no sensitivity and relay j is stuck due to current in the opposite direction in period 1 (case 9)**

This happens when fault currents at relays i and j go in the opposite

direction in the first period, and relays i and j are not sensitive in the first period.

Relays i and j are sensitive at second period.



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Partial operation is achieved when all the following conditions are achieved:

1.- In first period, fault currents Ijkh and Iikh go in the opposite direction if angle difference between fault currents Ijkh and Iikh is greater than an admissible polarization angle f.

|qjkh – qikh|> f Is true, or |qjkh – qikh|< f Is NOT true

2.- In second periods, fault currents I’ikh and I’jkh go in the same direction if angle difference between fault currents I’jkh and Iikh is NOT greater than an admissible polarization angle f.

|q'jkh – q'ikh|> f Is NOT true, or |q'jkh – q'ikh|< f Is true

3.- If

bjkh < 0 Is NOT true, or bjkh > 0 is true and, relay j is sensitive at period

bikh < 0 Is true, or bikh > 0 Is NOT true and, relay i is NOT sensitive at period 1

b'jkh < 0 Is NOT true, or b'jkh > 0 Is true and, relay j is sensitive at period 2

b'ikh < 0 Is NOT true, or b'ikh > 0 Is true and, relay i is sensitive at period 2

In this case a coordination interval S exists and a primary time T\*i can be calculated.

Therefore, the corresponding classification code is:

%%---------------------------------------------------------

% Type 5c - Case 9

for g=1:length(C1(:,1))

if abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) > qmax &... %period 1: yes reverse current relay j

abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax &... %period 2: no reverse current relay j

beta(C1(g,1),C1(g,3)) < 0 &...%period 1: yes loss of sensitivity relay j

betap(C1(g,1),C1(g,3)) > 0 &...%period 2: no loss of sensitivity relay j

beta(C1(g,2),C1(g,3)) < 0 &...%period 1: yes loss of sensitivity relay i

betap(C1(g,2),C1(g,3)) >0 %period 2: no loss of sensitivity relay iif abs(theta(C1(g,1),C1(g,3))-theta(C1(g,2),C1(g,3))) > qmax & abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax & beta(C1(g,1),C1(g,3)) > 0 & betap(C1(g,1),C1(g,3)) > 0 & beta(C1(g,2),C1(g,3)) < 0 & betap(C1(g,2),C1(g,3)) > 0 & beta(C1(g,4),C1(g,3))\*D(C1(g,4))

flag=flag+1;

fl(9)=fl(9)+1;

S(flag)=betap(C1(g,1),C1(g,3))\*D(C1(g,1))-betap(C1(g,2),C1(g,3))\*D(C1(g,2))-0\*gammappp(C1(g,4),C1(g,1),C1(g,2),C1(g,3))\*D(C1(g,4));

Tj=beta(C1(g,1),C1(g,3))\*D(C1(g,1));

Ti=beta(C1(g,2),C1(g,3))\*D(C1(g,2));

Tqq=beta(C1(g,4),C1(g,3))\*D(C1(g,4));

Tpj=betap(C1(g,1),C1(g,3))\*D(C1(g,1));

Tpi=betap(C1(g,2),C1(g,3))\*D(C1(g,2));

Tix(flag)=Tpi;

Tjx(flag)=Tpj;

end

end

% End Type 5c - Case 9

**Type 6: No fault detection**

**Type 6a: Relay p is stuck due to current in the opposite direction in period 1 (case 10)**

This happens when fault currents at q and p go in the opposite direction at first period, and

p is sensitive at first period



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Normal operation is achieved when the following conditions are achieved:

1.- In the first period, fault current Ipkh goes in the opposite direction of Iqkh if angle difference between fault currents Ipkh and Iqkh is NOT greater than an admissible polarization angle f.

|qpkh – qqkh|> f is true, or |qpkh – qqkh|< f is NOT true

2.- In the first period, backup relay p is sensitive if fault current magnitude Ipkh is NOT lower than its pick-up current Pp. In this case, the ratio Iqkh / Pq yields a positive b parameter. Therefore, sensitivity is achieved at relay p if:

bpkh < 0 Is NOT true, or bpkh > 0 is true

Notice that relay q is always sensitive at first period.

In case 1 a coordination interval S exists and a primary time Tq can be calculated.

Therefore, the corresponding classification code is:

In this case a coordination interval S does not exist and a primary time Tq can be calculated.

Notice that Tp\* cannot be calculated.

Therefore, the corresponding classification code is:

%% Type 6a - Case 10

for g=1:length(C2(:,1))

if abs(theta(C2(g,1),C2(g,3))-theta(C2(g,2),C2(g,3))) > qmax &...period 1:yes reverse current relay p

beta(C2(g,1),C2(g,3)) > 0 %period 1: no loss of sensitivity relay p

fl(10)=fl(10)+1;

flag=flag+1;

Tq(flag)=beta(C2(g,2),C2(g,3))\*D(C2(g,2));

end

end%

% End Type 6a - Case 10

**Type 6: No fault detection**

**Type 6b: Relay j is stuck due to current in the opposite direction in period 2 (case 11)**

Type 6b, relay j current goes in the opposite direction

This happens when fault currents at relays i and j go in the same direction in period 2, and

relay j is not sensitive in period 2.



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Normal operation is achieved when all the following conditions are achieved:

1.- In period 2, fault current I’jkh goes in the opposite direction of I’ikh if angle difference between fault currents I’jkh and I’ikh is greater than an admissible polarization angle f.

|q'jkh – q'ikh|> f is true, or |q'jkh – q'ikh|< f is NOT true

In this case a coordination interval S does not exist and a primary time T\*i can be calculated. T\*j cannot be calculated

%%---------------------------------------------------------

% Type 6b - Case 11

for g=1:length(C1(:,1))

if

abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) > qmax %period 2:yes reverse current relay j

fl(11)=fl(11)+1;

end

end

% End Type 6b - Case 11

**Type 6: No fault detection**

**Type 6c: Relay p is stuck due to no sensitivity in period 1 (case 12)**

This happens when fault currents at q and p go in the same direction at first period, and

relay p is not sensitive at first period



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Normal operation is achieved when the following conditions are achieved:

1.- In the first period, fault current Ipkh goes in the same direction than Iqkh if angle difference between fault currents Ipkh and Iqkh is NOT greater than an admissible polarization angle f.

|qpkh – qqkh|> f is NOT true, or |qpkh – qqkh|< f Is true

2.- In the first period, backup relay p is not sensitive if fault current magnitude Ipkh is lower than its pick-up current Pp. In this case, the ratio Iqkh / Pq yields a negative b parameter. Therefore, no sensitivity is achieved at relay p if:

bpkh < 0 is true, or bpkh > 0 is NOT true

In this case a coordination interval S does not exist and a primary time Tq can be calculated.

Notice that Tp\* cannot be calculated.

Therefore, the corresponding classification code is:

%%---------------------------------------------------------

% Type 6c - Case 12

for g=1:length(C2(:,1))

if abs(theta(C2(g,1),C2(g,3))-theta(C2(g,2),C2(g,3))) < qmax &...period 1:no reverse current relay p

beta(C2(g,1),C2(g,3)) < 0 %period 1: yes loss of sensitivity relay p

fl(12)=fl(12)+1;

flag=flag+1;

Tq(flag)=beta(C2(g,2),C2(g,3))\*D(C2(g,2));

end

end

% End Type 6c - Case 12

**Type 6: No fault detection**

**Type 6d: Relay p is stuck due to current in the opposite direction and no sensitivity in period 1 (case 13)**

This happens when fault currents at q and p go in the opposite direction at first period, and

relay p is not sensitive at first period



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Normal operation is achieved when the following conditions are achieved:

1.- In the first period, fault current Ipkh goes in the opposite direction than Iqkh if angle difference between fault currents Ipkh and Iqkh is greater than an admissible polarization angle f.

|qpkh – qqkh|> f is true, or |qpkh – qqkh|< f is NOT true

2.- In the first period, backup relay p is not sensitive if fault current magnitude Ipkh is lower than its pick-up current Pp. In this case, the ratio Iqkh / Pq yields a negative b parameter. Therefore, no sensitivity is achieved at relay p if:

bpkh < 0 is true, or bpkh > 0 is NOT true

In this case a coordination interval S does not exist and a primary time Tq can be calculated.

Notice that Tp\* cannot be calculated.

Therefore, the corresponding classification code is:

%%---------------------------------------------------------

% Type 6d - Case 13

for g=1:length(C2(:,1))

if abs(theta(C2(g,1),C2(g,3))-theta(C2(g,2),C2(g,3))) > qmax &...period 1:yes reverse current relay p

beta(C2(g,1),C2(g,3)) < 0

%period 1: yes loss of sensitivity relay p

fl(13)=fl(13)+1;

flag=flag+1;

Tq(flag)=beta(C2(g,2),C2(g,3))\*D(C2(g,2));

end

end

% End of 6d - Case 13

**Type 6: No fault detection**

**Type 6e: Relay i is stuck due to current in the opposite direction in period 2 (case 14)**

This happens relay i is not sensitive in period 2.



Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Normal operation is achieved when all the following conditions are achieved:

1.- In period 2:

b'ikh < 0 is true, or b'ikh > 0 is NO true and, relay i is no sensitive at period 2

In this case a coordination interval S does not exist and a primary time T\*i cannot be calculated.

%%---------------------------------------------------------

% Type 6e - Case 14

for g=1:length(C1(:,1))

if betap(C1(g,2),C1(g,3)) < 0 %period 2: yes loss of sensitivity relay i

fl(15)=fl(15)+1;

end

end

% End of Type 6e - Case 14

**Type 6: No fault detection**

**Type 6f: Relay j is stuck due to no sensitivity in period 2 (case 15)**

This happens when relay j is not sensitive in period 2.

Considering a fault at line k at a location h such that Relay B=q operates faster than relay A=i. Normal operation is achieved when all the following conditions are achieved:

1.- In period 2:

b'jkh < 0 is true, or b'jkh > 0 is NO true and, relay j is no sensitive at period 2

In this case a coordination interval S does not exist and a primary time T\*i can be calculated. T\*j cannot be calculated

%%---------------------------------------------------------

% Type 6f - Case 15

for g=1:length(C1(:,1))

if abs(thetap(C1(g,1),C1(g,3))-thetap(C1(g,2),C1(g,3))) < qmax & ... %period 2:no reverse current relay j

betap(C1(g,1),C1(g,3)) < 0 %period 2: yes loss of sensitivity relay j

fl(14)=fl(14)+1;

end

end

% End of Type 6f - Case 15