ABSTRACT

With the day to day increase of the power and the increasing rate of industrialization, the amount of power to be developed and the safety of the power transformer have increased manifolds. For optimum results it is required to have nearly a no fault operation of power transformer. False tripping of circuit breaker due to Inrush current is a major problem in power system and it directly effects on the reliability of power supply. The objective of this paper is to design a controller or method which can discriminate between Inrush and Fault current to avoid false tripping of circuit breaker. Many methods used for identifying inrush current, they have their merits and demerits. But still there is no boundary of improvement in this field. It may be stated emphasis that inrush current is a sector to give attention to find still better way of identification and mitigation. Fuzzy controller being an intelligent controller could be used for the purpose of detection of inrush and fault current. Inrush current consists of large magnitude of second harmonic; by analysis of second harmonic and with fuzzy logic we have obtained accurate and more useful results.

Keywords: Inrush current, Second Harmonics, Fuzzification, Fuzzy Controller

1. INTRODUCTION

Power transformers are one of the most important, expensive and essential elements in power system. In today’s world of technology and comfort, the need of power and its protection has increased manifolds. Reliability and stability of the whole power system are the primary issues concerning transformers. Therefore, the continuity of transformer operation and their protection are of vital importance in maintaining the reliability of power supply and this require the protective relays with high dependability (no missing operation), security (no false tripping), and quick speed of operation (short fault clearing time). For this purpose, differential protection has been employed as the primary protection of most power transformer for many years.

The relay which is used to check the difference between the output and input currents for power system current is known as differential relay. The difference amongst the currents may also be in phase angle or in magnitude or in each. For hale and energetic operation, angle and magnitude variations must be zero. In case there's a difference which difference go beyond some value, the relay can work and interconnected electrical fuse can disconnect. Since the Inrush current have very high magnitude, differential relay cannot discriminate between the inrush current and fault current and result is false tripping of circuit breaker. Therefore it is required to develop some method or technique which can discriminate between fault and inrush current to avoid the false tripping of differential relay and hence improve the reliability of power supply. The magnetizing inrush current has high magnitude of second harmonic component; it becomes very important to study the magnitude of second harmonic of inrush and different fault currents. Matlab simulation is the most preferred software tool for determining the magnitude of different harmonics by using Fourier transform. The Fourier Transform is a tool that breaks a waveform (a function or signal) into an alternate representation, characterized by sine and cosines. By using FT tools we can easily realized the desired frequency of any signal. In this paper, we analyse the magnitude of second harmonic in inrush and for different fault currents and on the basis of this result, we discriminate the inrush current from fault currents.

2. INRUSH CURRENT

Literally “Inrush” means “that rushes in”

An inrush current is the surge of transient current that rushes in a transformer when transformer is energized. These currents are of high magnitude, harmonic-rich generated when transformer cores are driven into saturation. According to Faraday’s law of Electromagnetic Induction the voltage induced across the winding is given as
\[ e = \frac{d\varphi}{dt} \] where \( \varphi \) is the flux in the core.

\[ e = E \cdot \sin \omega t = \frac{d\varphi}{dt} \Rightarrow \varphi = \int e \cdot dt = E \int \sin \omega t \cdot dt \]

Hence the flux will be integral of the voltage wave. If the transformer is switched on at the instant of voltage zero, the flux wave is initiated from the same origin as voltage waveform, the value of flux at the end of first half cycle of the voltage waveform will be,

\[ \varphi_m' = E \int_0^\frac{\pi}{\omega} \sin \omega t \cdot dt = \varphi_m \int_0^\frac{\pi}{\omega} \sin \omega t \cdot d(\omega t) = 2\varphi_m \]

where \( \varphi_m \) is the maximum value of steady state flux. That means flux become double to its maximum value. The transformer core is generally saturated just above the maximum steady state value of flux. But during switching on the transformer the maximum value of flux will jump to double of its steady state maximum value. As, after steady state maximum value of flux, the core becomes saturated, the current required to produced rest of flux will be very high. So transformer primary will draw a very high peaky current from the source which is called magnetizing inrush current in transformer or simply inrush current in transformer.

3. Magnitude of Second Harmonics in Inrush and Fault currents at different Instant angle of fault obtained by using Matlab Simulink Model.

The single diagram of the power system model considered for Simulation study is shown in Figure 1

![Figure 1 Single Line diagram of the Transmission Line](image1)

The Matlab Simulink Model of the transmission line fed from one end is shown in Figure 2

![Figure 2 Matlab Simulink Model of the transmission line](image2)

The magnitude of both Inrush and Fault current are very high, therefore differential relay fails to differentiate between them and always tripping occurs which may be false tripping in case of Inrush current. The simulation results compared with each other, finally we reached to conclusion that on the basis of Magnitude of System current it is not possible to discriminate the Inrush and fault current. Magnitude of Second harmonic component of System current is better option for differentiate the Inrush to Fault current. After that we have framed Mamdani model of rule base.
Table 1: Magnitude of Second Harmonics in Inrush and Fault currents at different switching angle

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Angle</th>
<th>Normal Condition</th>
<th>Inrush Current</th>
<th>LG Fault</th>
<th>LL Fault</th>
<th>LLG Fault</th>
<th>LLLG Fault</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 degree</td>
<td>0.007269</td>
<td>198.2</td>
<td>0.5862</td>
<td>28.49</td>
<td>51.01</td>
<td>68.12</td>
</tr>
<tr>
<td>2</td>
<td>30 degree</td>
<td>0.07979</td>
<td>210.4</td>
<td>33.69</td>
<td>54.58</td>
<td>66.87</td>
<td>75.49</td>
</tr>
<tr>
<td>3</td>
<td>60 degree</td>
<td>0.007269</td>
<td>229</td>
<td>59.11</td>
<td>65.54</td>
<td>66.18</td>
<td>68.12</td>
</tr>
<tr>
<td>4</td>
<td>90 degree</td>
<td>0.07979</td>
<td>143.2</td>
<td>68.66</td>
<td>58.91</td>
<td>72.96</td>
<td>75.45</td>
</tr>
<tr>
<td>5</td>
<td>120 degree</td>
<td>0.007269</td>
<td>130.4</td>
<td>59.11</td>
<td>36.37</td>
<td>60.49</td>
<td>68.12</td>
</tr>
<tr>
<td>6</td>
<td>150 degree</td>
<td>0.07979</td>
<td>205.1</td>
<td>35.06</td>
<td>4.988</td>
<td>30.81</td>
<td>75.47</td>
</tr>
<tr>
<td>7</td>
<td>180 degree</td>
<td>0.003117</td>
<td>130.3</td>
<td>0.8134</td>
<td>28.53</td>
<td>51.86</td>
<td>68.12</td>
</tr>
</tbody>
</table>

It is clear from above data the magnitude of second harmonic in fault current are quite less compared to inrush case, Hence by using Magnitude of Second Harmonic we can easily differentiate between inrush and fault current.

4. Fuzzy Controller

In the fuzzy controller there are three blocks input, output and rule base. We have made two different inputs. The first input is the switching angle ranging from -15 to 195 degree. The second input is the magnitude of second harmonic with range from 0 to 250.

In the output block we have only one single output with six different parameters, Normal condition with range from 0 to 1, Inrush current with range from 1 to 2, LG fault with range from 2 to 13, LL fault with range from 3 to 4, LLG fault with range from 4 to 5 and LLLG fault with range from 5 to 6.

The third block in the fuzzy controller is the rule base in which we have framed different rules. The third block in the fuzzy controller is the rule base in which we have framed different rules.

![Figure 3 Block diagram of Fuzzy controller](image)

Table 2: Input Parameter: Switching Angle

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_0</td>
<td>Triangular</td>
<td>[-15 0 15]</td>
</tr>
<tr>
<td>A_15</td>
<td>Triangular</td>
<td>[0 15 30]</td>
</tr>
<tr>
<td>A_30</td>
<td>Triangular</td>
<td>[15 30 45]</td>
</tr>
<tr>
<td>A_45</td>
<td>Triangular</td>
<td>[30 45 60]</td>
</tr>
<tr>
<td>A_60</td>
<td>Triangular</td>
<td>[45 60 75]</td>
</tr>
<tr>
<td>A_75</td>
<td>Triangular</td>
<td>[60 75 90]</td>
</tr>
<tr>
<td>A_90</td>
<td>Triangular</td>
<td>[75 90 105]</td>
</tr>
<tr>
<td>A_105</td>
<td>Triangular</td>
<td>[90 105 120]</td>
</tr>
<tr>
<td>A_120</td>
<td>Triangular</td>
<td>[105 120 135]</td>
</tr>
<tr>
<td>A_135</td>
<td>Triangular</td>
<td>[120 135 150]</td>
</tr>
<tr>
<td>A_150</td>
<td>Triangular</td>
<td>[135 150 165]</td>
</tr>
<tr>
<td>A_165</td>
<td>Triangular</td>
<td>[150 165 180]</td>
</tr>
<tr>
<td>A_180</td>
<td>Triangular</td>
<td>[165 180 195]</td>
</tr>
</tbody>
</table>
Table 3: Input Parameter: Magnitude of Second Harmonic

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_1$</td>
<td>Triangular</td>
<td>[0 0.25 .5]</td>
</tr>
<tr>
<td>$H_2$</td>
<td>Triangular</td>
<td>[0.5 0.75 1]</td>
</tr>
<tr>
<td>$H_3$</td>
<td>Triangular</td>
<td>[1 3 5]</td>
</tr>
<tr>
<td>$H_4$</td>
<td>Triangular</td>
<td>[5 15 25]</td>
</tr>
<tr>
<td>$H_5$</td>
<td>Triangular</td>
<td>[25 27.5 30]</td>
</tr>
<tr>
<td>$H_6$</td>
<td>Triangular</td>
<td>[30 32.5 35]</td>
</tr>
<tr>
<td>$H_7$</td>
<td>Triangular</td>
<td>[35 37.5 40]</td>
</tr>
<tr>
<td>$H_8$</td>
<td>Triangular</td>
<td>[40 42.5 45]</td>
</tr>
<tr>
<td>$H_9$</td>
<td>Triangular</td>
<td>[45 47.5 50]</td>
</tr>
<tr>
<td>$H_{10}$</td>
<td>Triangular</td>
<td>[50 52.5 55]</td>
</tr>
<tr>
<td>$H_{11}$</td>
<td>Triangular</td>
<td>[55 57.5 60]</td>
</tr>
<tr>
<td>$H_{12}$</td>
<td>Triangular</td>
<td>[60 62.5 65]</td>
</tr>
<tr>
<td>$H_{13}$</td>
<td>Triangular</td>
<td>[65 67.5 70]</td>
</tr>
<tr>
<td>$H_{14}$</td>
<td>Triangular</td>
<td>[70 72.5 75]</td>
</tr>
<tr>
<td>$H_{15}$</td>
<td>Triangular</td>
<td>[75 97.5 120]</td>
</tr>
<tr>
<td>$H_{16}$</td>
<td>Triangular</td>
<td>[120 180 240]</td>
</tr>
</tbody>
</table>

Table 4: Output parameter: Status of System

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC (Normal Condition)</td>
<td>Triangular</td>
<td>[0 .5 1]</td>
</tr>
<tr>
<td>IC (Inrush Current)</td>
<td>Triangular</td>
<td>[1 1.5 2]</td>
</tr>
<tr>
<td>LG (Line to Ground Fault)</td>
<td>Triangular</td>
<td>[2 2.5 3]</td>
</tr>
<tr>
<td>LL (Line to Line Fault)</td>
<td>Triangular</td>
<td>[3 3.5 4]</td>
</tr>
<tr>
<td>LLG (Double Line to Ground Fault)</td>
<td>Triangular</td>
<td>[4 4.5 5]</td>
</tr>
<tr>
<td>LLLG(Triple Line to Ground Fault)</td>
<td>Triangular</td>
<td>[5 5.5 6]</td>
</tr>
</tbody>
</table>

Rule Base:
1. If (x is $A_{0}$) and (y is $H_1$) then (z is NC)
2. If (x is $A_{15}$) and (y is $H_1$) then (z is NC)
3. If (x is $A_{30}$) and (y is $H_1$) then (z is NC)
4. If (x is $A_{45}$) and (y is $H_1$) then (z is NC)
5. If (x is $A_{60}$) and (y is $H_1$) then (z is NC)
6. If (x is $A_{75}$) and (y is $H_1$) then (z is NC)
7. If (x is $A_{90}$) and (y is $H_1$) then (z is NC)
8. If (x is $A_{105}$) and (y is $H_1$) then (z is NC)
9. If (x is $A_{120}$) and (y is $H_1$) then (z is NC)
10. If (x is $A_{135}$) and (y is $H_1$) then (z is NC)
11. If (x is $A_{150}$) and (y is $H_1$) then (z is NC)
12. If (x is $A_{165}$) and (y is $H_1$) then (z is NC)
13. If (x is $A_{180}$) and (y is $H_1$) then (z is NC)
14. If (x is $A_{0}$) and (y is $H_{16}$) then (z is IC)
15. If (x is $A_{15}$) and (y is $H_{16}$) then (z is IC)
16. If (x is $A_{30}$) and (y is $H_{16}$) then (z is IC)
17. If (x is $A_{45}$) and (y is $H_{16}$) then (z is IC)
18. If (x is $A_{60}$) and (y is $H_{16}$) then (z is IC)
19. If (x is $A_{75}$) and (y is $H_{16}$) then (z is IC)
20. If (x is $A_{90}$) and (y is $H_{10}$) then (z is IC)
21. If (x is $A_{105}$) and (y is $H_{10}$) then (z is IC)
22. If (x is $A_{120}$) and (y is $H_{10}$) then (z is IC)
23. If (x is $A_{135}$) and (y is $H_{10}$) then (z is IC)
24. If (x is $A_{150}$) and (y is $H_{10}$) then (z is IC)
25. If (x is $A_{165}$) and (y is $H_{10}$) then (z is IC)
26. If (x is $A_{180}$) and (y is $H_{10}$) then (z is IC)
27. If (x is $A_{180}$) and (y is $H_{2}$) then (z is LG)
28. If (x is $A_{180}$) and (y is $H_{2}$) then (z is LL)
29. If (x is $A_{180}$) and (y is $H_{10}$) then (z is LLG)
30. If (x is $A_{180}$) and (y is $H_{10}$) then (z is LLLG)
31. If (x is $A_{180}$) and (y is $H_{10}$) then (z is LG)
32. If (x is $A_{180}$) and (y is $H_{10}$) then (z is LL)
33. If (x is $A_{180}$) and (y is $H_{10}$) then (z is LLG)
34. If (x is $A_{180}$) and (y is $H_{10}$) then (z is LLLG)
35. If (x is $A_{180}$) and (y is $H_{10}$) then (z is LL)
36. If (x is $A_{180}$) and (y is $H_{12}$) then (z is LL)
37. If (x is $A_{180}$) and (y is $H_{12}$) then (z is LLG)
38. If (x is $A_{180}$) and (y is $H_{14}$) then (z is LLLG)
39. If (x is $A_{180}$) and (y is $H_{14}$) then (z is LG)
40. If (x is $A_{180}$) and (y is $H_{14}$) then (z is LL)
41. If (x is $A_{180}$) and (y is $H_{14}$) then (z is LLG)
42. If (x is $A_{180}$) and (y is $H_{14}$) then (z is LLLG)
43. If (x is $A_{180}$) and (y is $H_{14}$) then (z is LG)
44. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LL)
45. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LG)
46. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLL)
47. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
48. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LG)
49. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LL)
50. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
51. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LG)
52. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LL)
53. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLG)
54. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
55. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LG)
56. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LL)
57. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
58. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
59. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LG)
60. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LL)
61. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
62. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LG)
63. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LL)
64. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLL)
65. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
66. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LG)
67. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LL)
68. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
69. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
70. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LG)
71. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LL)
72. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLL)
73. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
74. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
75. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LG)
76. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LL)
77. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
78. If (x is $A_{120}$) and (y is $H_{3}$) then (z is LLLG)
FIS Editor

Membership Function for first input “Switching Angle”:

Rule Viewer of FIS
5. Simulink Model of Power System with Fuzzy Controller

6. Fuzzy controller output and its significance

If output between 0 to 1 that means there is no Fault and Inrush current.
If output between 1 to 2 that means there is Inrush current.
If output between 2 to 3 that means there is LG Fault current.
If output between 3 to 4 that means there is LL Fault current.
If output between 4 to 5 that means there is LLG Fault current.
If output between 5 to 6 that means there is LLLG Fault current.

Some Results:

The output of Controller is 2.5 that mean Fault is LG Type.
The output of Controller is 1.5 that means there is Inrush current.

The output of Controller is 4.5 that mean Fault is LLG Type.

Conclusion
Simulation results show that proposed fuzzy logic classifier can successfully distinguish inrush current and fault current. Moreover, fuzzy logic classifier was able to classify different fault conditions viz. Line to line, line to ground ,line to line to ground fault. Hence, not only proposed fuzzy classifier can prevent false operation of differential protection relay but it can also distinguish various symmetrical and unsymmetrical faults.

Scope for Future Work
Implementation of same model to discriminate between internal fault and inrush current, Experimental verification of simulation result, Incorporation of neural network for classification.

References

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