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# Comparative Analysis Of Point Of Initiation Of Different Types Of Voltage Sag On Induction Motor Performance

**Divya Chauhan[1], Sandeep Kumar Goel[2]**

[1]*Ph.D. Scholar, Dept. Of Electrical Engineering, GBPUA&T, Pantnagar, Uttarakhand, India*
[2]*Professor, Dept. Of Electrical Engineering, GBPUA&T, Pantnagar, Uttarakhand, India*

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**Abstract –** *In this work a simulation based comparative study has been carried out for analysis of different types of voltage sag with their effect on induction motor performance. Voltage sag is basically classified by its magnitude, duration and point of voltage sag initiation on wave. This paper studies the influence of different voltage sag magnitude on different initial wave points. The influence of voltage sag on induction motor is observed in terms of current, torque peak value and speed loss. The effect of both symmetrical and unsymmetrical voltage sag intensity on performance of induction motor has been studied with different starting point. All the simulation work is performed in MATLAB-SIMULINK.*

***Key Words***: Induction Motor, Voltage Sag Types, Point of Initiation, Sag Magnitude, Sag Duration.

## 1. INTRODUCTION

Voltage sag is a considerable research topic and is one of the power quality issues that severely affect the performance of Induction motor in several ways. Nowadays more emphasis is provided to voltage sag related issues for voltage sensitive equipments for power and frequency requirement [1]. A voltage sag is basically defined as the decrement in RMS voltage value from 90% to 10% of nominal voltage value for a time period of greater than half cycle of power frequency with less than or equal to 1 minute, according to standards of IEEE, 1159-1995. Voltage sag can also be classified as symmetrical voltage sag or asymmetrical voltage sag depending on the basis of occurrence of particular type of fault [2].

The main cause of occurrence of symmetrical voltage sag is due to three phase faults or due to starting of large size induction machines. Symmetrical voltage sags are classified by equal magnitude of all individual phase voltages with their phasor values displaced by $120^0$. The main causes that results in unsymmetrical voltage sags are basically line to line faults, single line to ground faults or two line to ground faults. The effect of occurrence of voltage sag in Induction motor results in current and torque peak fluctuations with speed loss of the machine and these effects can be deducted between the point of sag initiation and its recovery instants.

### 1.1 System Description

In this work an induction motor of 10 hp rating with 400 V and 50 Hz has been taken for simulation work as shown in Figure 1. An effort is carried out to observe the results of symmetrical voltage sag initiation for different magnitude of voltage sags on induction motor and these results are compared with the results obtained for effects of unsymmetrical voltage sag on same machine. Characterisation of different types of voltage sags, comparison of effects of point of voltage sag initiation and conclusion with obtained results are described in Section 2, 3 and 4 respectively.

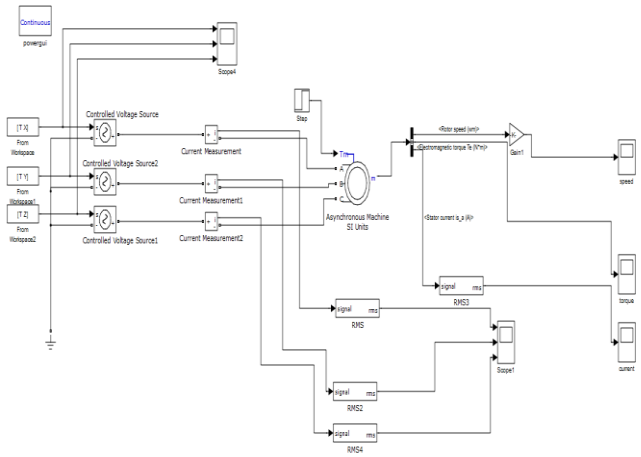
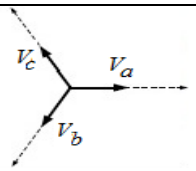
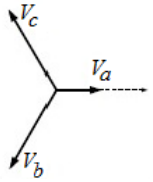
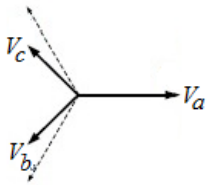
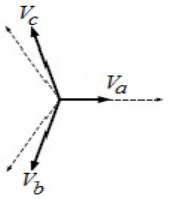
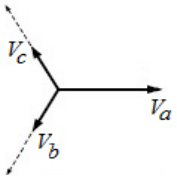
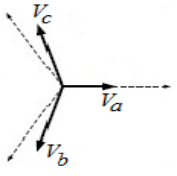
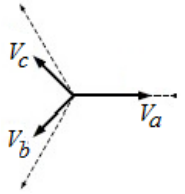



**Figure - 1:** Schematic diagram for Simulation model of Induction Motor

## 2. CHARACTERIZATION OF VARIOUS VOLTAGE SAG

In case of three phase load the occurrence of different types of voltage sag can be characterized into following seven types namely Type A, B, C, D, E, F, and Type G [8] . Only Type A sag is the symmetrical type of sag and rest of the sag are unsymmetrical type of voltage sag. Table 1 represents phasor diagrams for different types of voltage sag along with their equations. Sag magnitude is represented by alphabet h having its value between 0 to 1.

**Table -1:** Types of Voltage Sag Classification

| Types | Voltage Equations | Phasor Diagrams |
|---|---|---|
| A | $\bar{V}_a = V$<br>$\bar{V}_b = -\frac{1}{2}E_1 - j\frac{\sqrt{3}}{2}V$<br>$\bar{V}_c = -\frac{1}{2}E_1 + j\frac{\sqrt{3}}{2}V$ |  |
| B | $\bar{V}_a = V$<br>$\bar{V}_b = -\frac{1}{2}E_1 - j\frac{\sqrt{3}}{2}E_1$<br>$\bar{V}_c = -\frac{1}{2}E_1 + j\frac{\sqrt{3}}{2}E_1$ |  |
| C | $\bar{V}_a = E_1$<br>$\bar{V}_b = -\frac{1}{2}E_1 - j\frac{\sqrt{3}}{2}V$<br>$\bar{V}_c = -\frac{1}{2}E_1 + j\frac{\sqrt{3}}{2}V$ |  |
| D | $\bar{V}_a = V$<br>$\bar{V}_b = -\frac{1}{2}V - j\frac{\sqrt{3}}{2}E_1$<br>$\bar{V}_c = -\frac{1}{2}V + j\frac{\sqrt{3}}{2}E_1$ |  |
| E | $\bar{V}_a = E_1$<br>$\bar{V}_b = -\frac{1}{2}V - j\frac{\sqrt{3}}{2}V$<br>$\bar{V}_c = -\frac{1}{2}V + j\frac{\sqrt{3}}{2}V$ |  |
| F | $\bar{V}_a = E_1$<br>$\bar{V}_b = -\frac{1}{2}V - j\frac{\sqrt{3}}{2}V$<br>$\bar{V}_c = -\frac{1}{2}V + j\frac{\sqrt{3}}{2}V$ |  |
| G | $\bar{V}_a = \frac{2}{3}E_1 + \frac{1}{3}V$<br>$\bar{V}_b = -\frac{1}{3}E_1 - \frac{1}{6}V - j\frac{\sqrt{3}}{2}V$<br>$\bar{V}_c = -\frac{1}{3}E_1 - \frac{1}{6}V + j\frac{\sqrt{3}}{2}V$ |  |

It is observed that transients occurred in the voltage graph of system just after voltage sag initiation and after fault clearance [3], [4]. It is also observed that there are always chances of voltage phase shift or change in voltage sag type [5]. Therefore in this work for simplicity the shape of the voltage sag graph is taken as rectangular in shape. Also changes in voltage sag type are also not considered.

## 3. EFFECT OF POINT OF INITIATION ON WAVE AND VOLTAGE SAG MAGNITUDE

In the following work the performance of Induction motor has been observed in terms of the value of current peak value, torque peak value and loss in speed of machine after the sag initiation [6], [7]. Different sag magnitude values i.e. ( h = 0.1, 0.5, 0.8 ) are taken to observe the effect of various initiation points on the wave for different types of sags with different magnitudes as shown in Figure 2 to 6 in terms of torque peak. It can be observed that for sag Type A there is no effect on torque peak value for point of initiation of sag. For sag Type B and Type D the torque peak values are maximum when angle for initiation of sag is $90^0$ but in case of Type C and Type E it is maximum at $0^0$.

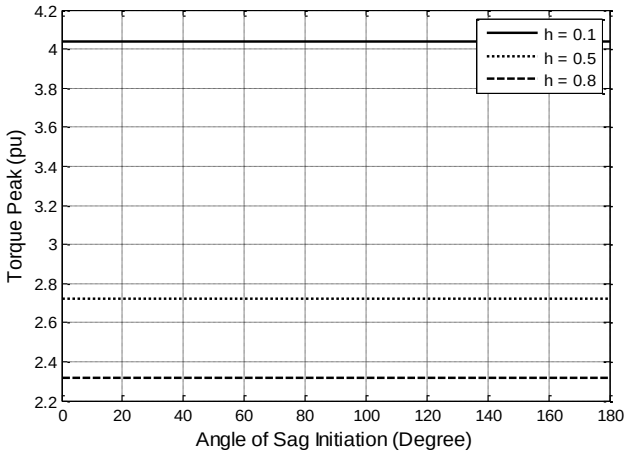



**Figure – 2:** Torque peak for Sag Type A for different initial point and magnitude

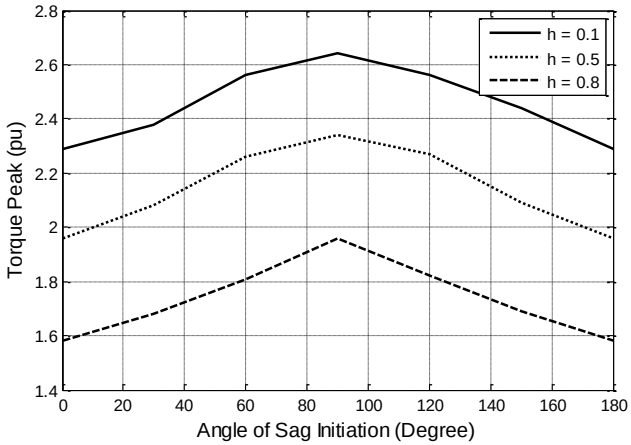



**Figure – 3:** Torque peak for Sag Type B for different initial point and magnitude

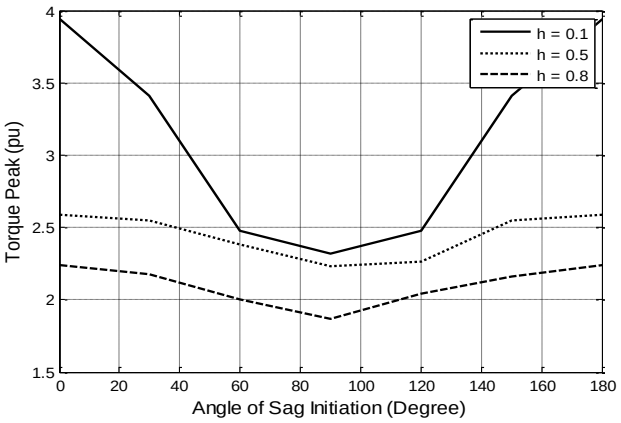



**Figure – 4:** Torque peak for Sag Type C for different initial point and magnitude

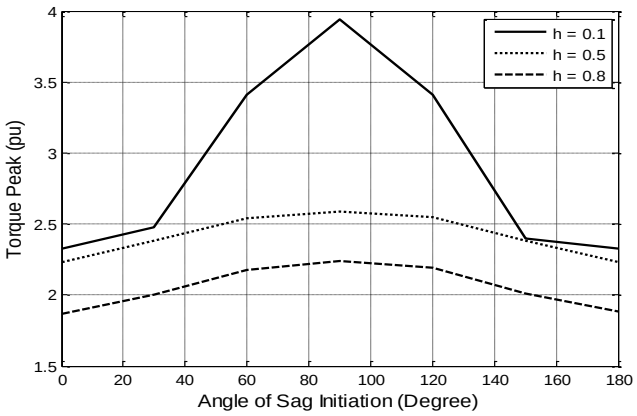



**Figure – 5:** Torque peak for Sag Type D for different initial point and magnitude

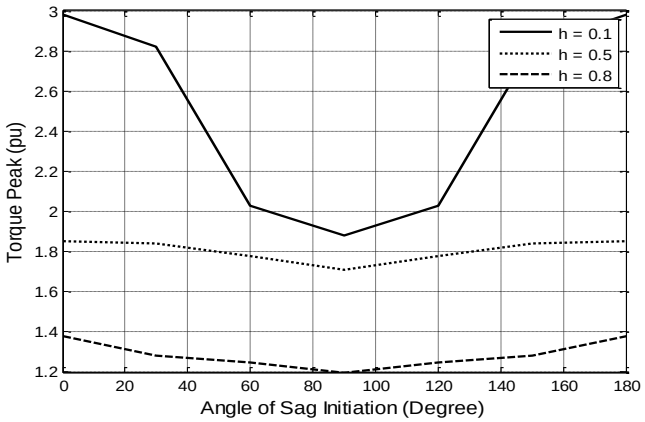



**Figure – 6:** Torque peak for Sag Type E for different initial point and magnitude

In figures 7 and 11 torque peak values for Sag Type F and Type G are shown. The shape of graphs are similar to that of Type D and Type E respectively.

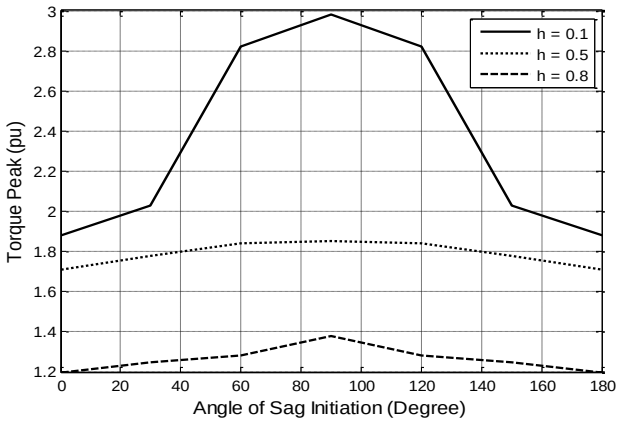



**Figure – 7:** Torque peak for Sag Type F for different initial point and magnitude

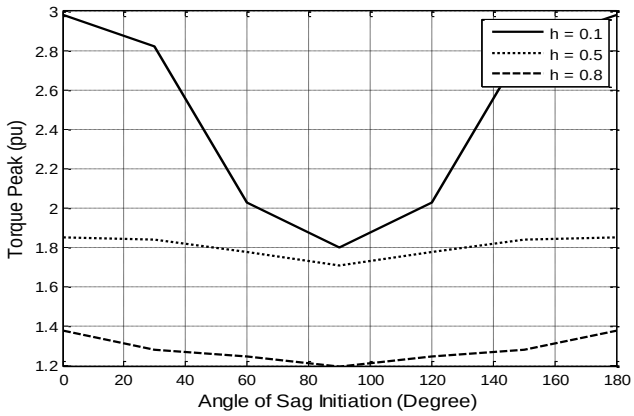



**Figure – 8:** Torque peak for Sag Type G for different initial point and magnitude

The following figures from 9 to 15 shows the effect of different initial points on the wave for current peak values.

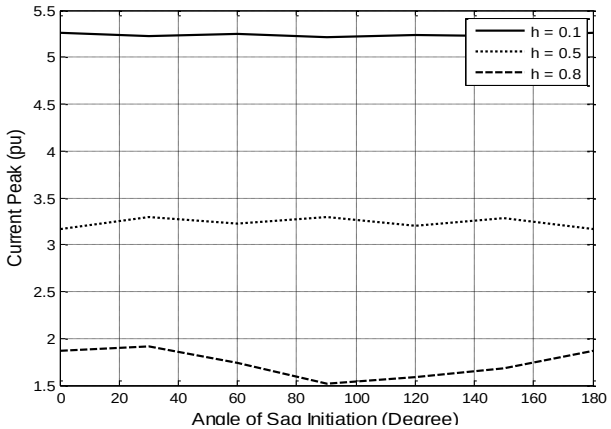



**Figure – 9:** Current peak for Sag Type A for different initial point and magnitude

Here it can be analyzed that in case of symmetrical sag Type A there is only a slight variation in magnitude for current peak values.

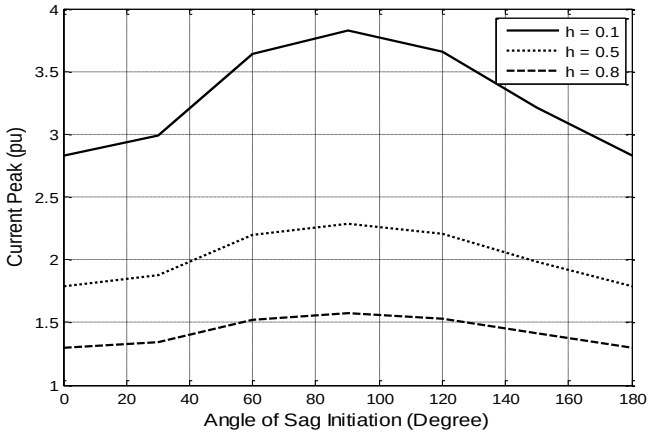



**Figure – 10:** Current peak for Sag Type B for different initial point and magnitude

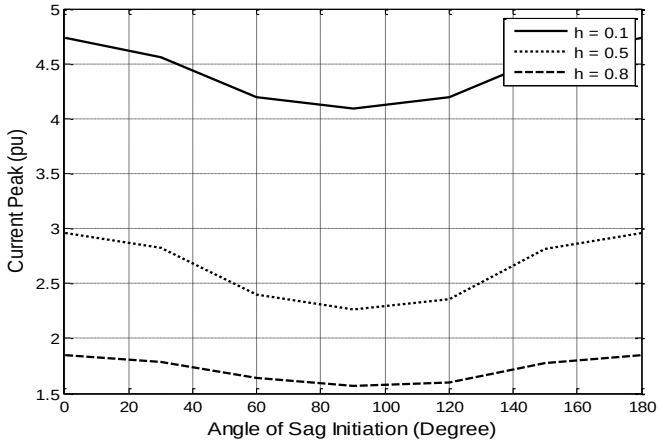



**Figure – 11:** Current peak for Sag Type C for different initial point and magnitude

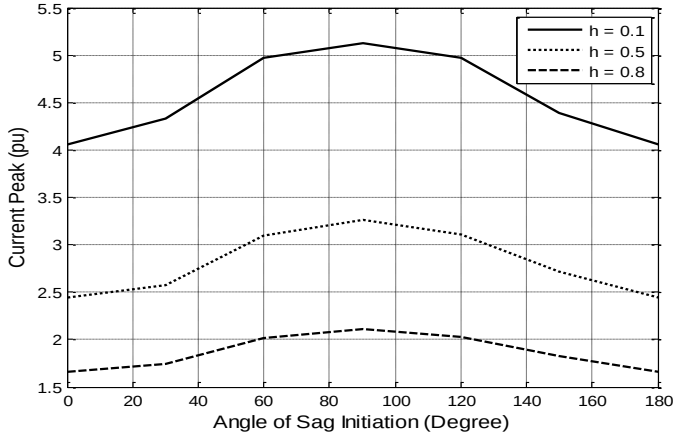



**Figure – 12:** Current peak for Sag Type D for different initial point and magnitude

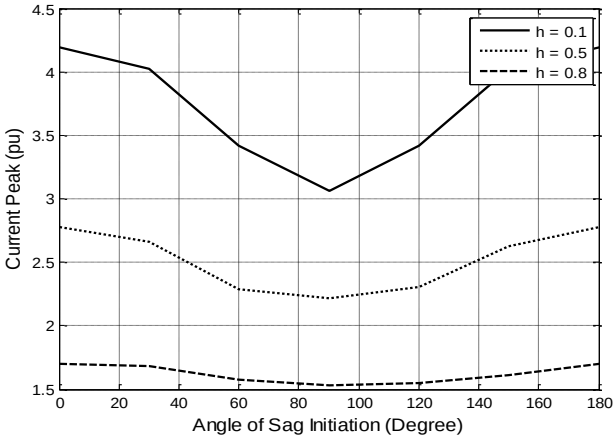



**Figure – 13:** Current peak for Sag Type E for different initial point and magnitude

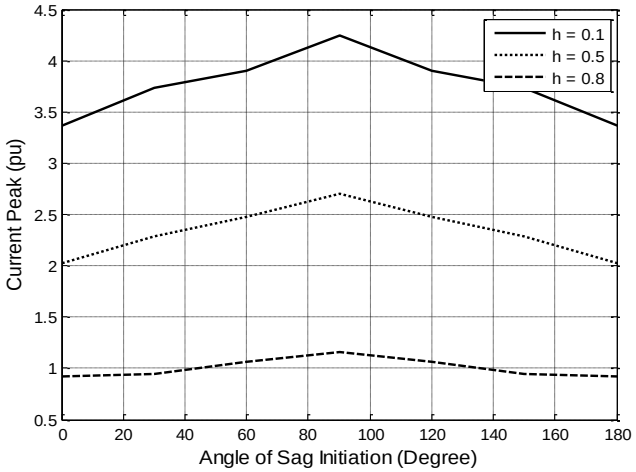



**Figure – 14:** Current peak for Sag Type F for different initial point and magnitude

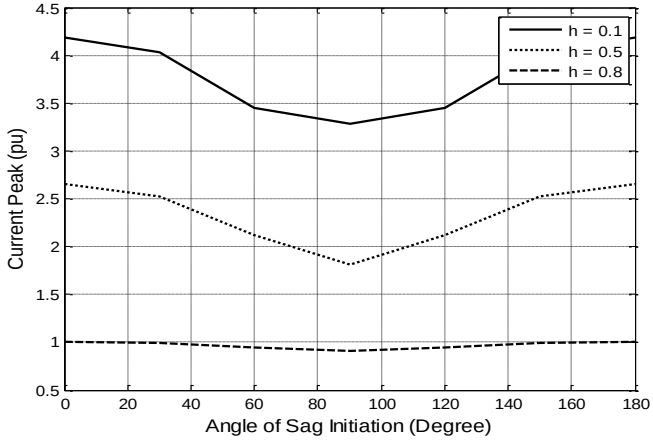



**Figure – 15:** Current peak for Sag Type G for different initial point and magnitude

For sag Type B and Type D, the value for current peaks are maximum at initiation angle of $90^0$ while for sag Type C and Type E, this value is maximum for initiation angle of $0^0$. Similarly in case of Sag Type F and Type G. Now as shown in Figure 16, in case of speed loss of machine there is no effect of initiation angle has been analyzed for sag Type A.

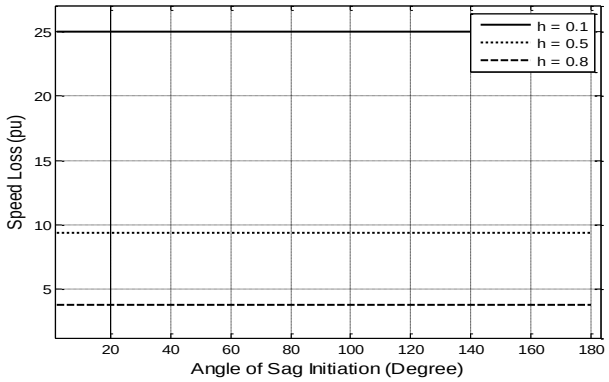



**Figure – 16:** Speed loss peak for Sag Type A for different initial point and magnitude

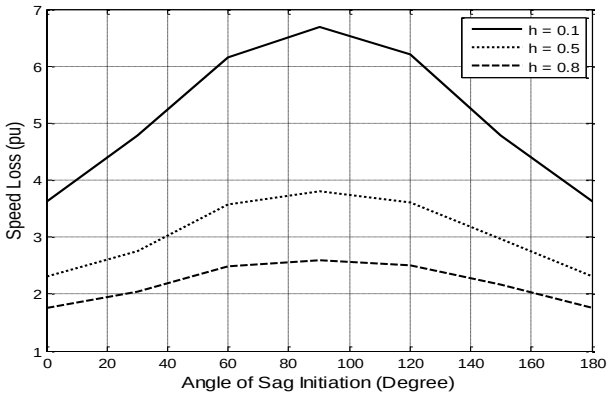



**Figure – 17:** Speed loss peak for Sag Type B for different initial point and magnitude

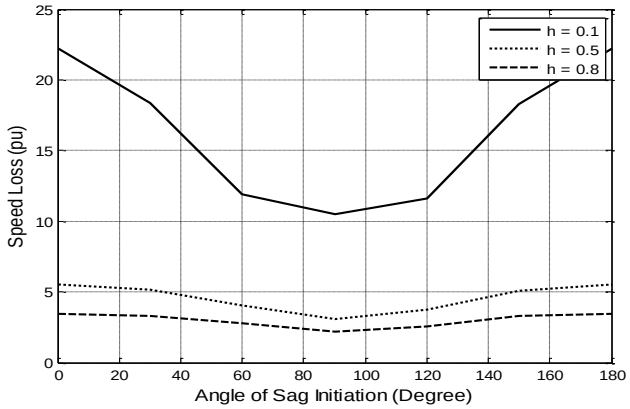



**Figure – 18:** Speed loss peak for Sag Type C for different initial point and magnitude

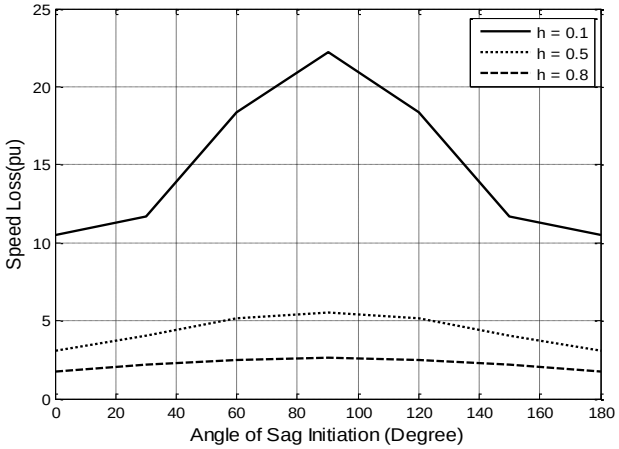



**Figure – 19:** Speed loss peak for Sag Type D for different initial point and magnitude

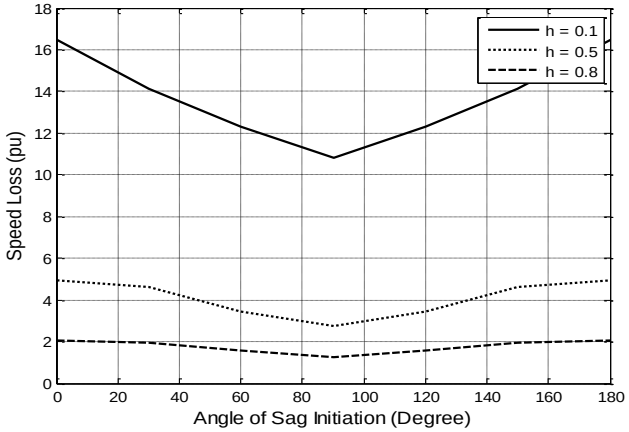



**Figure – 20:** Speed loss peak for Sag Type E for different initial point and magnitude

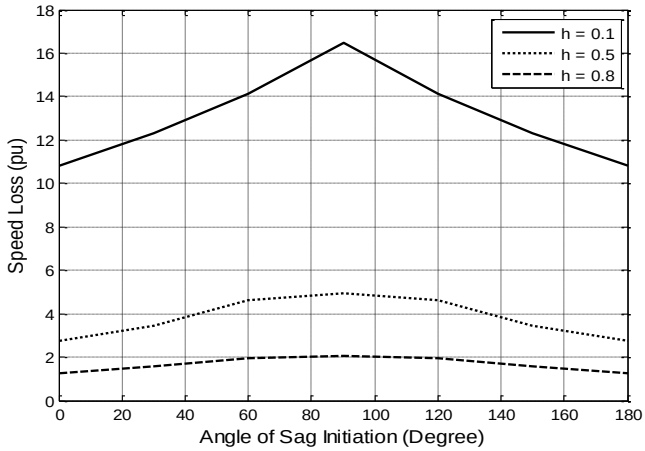



**Figure – 21:** Speed loss peak for Sag Type F for different initial point and magnitude

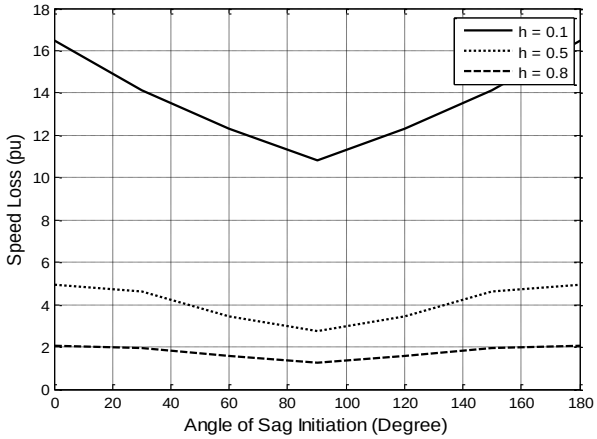



**Figure – 22:** Speed loss peak for Sag Type G for different initial point and magnitude

The maximum speed loss in machine occurs for initiation angle of $90^0$ for sag Type B and Type D but in case of Type F this value is $90^0$ with different shape and slope of graph. In case of sag Type C, Type E and Type G, speed loss in machine is maximum for initiation angle of $0^0$.

We can also observe that there is an increment in torque peak value, current peak value and speed loss of machine when the magnitude of remaining voltage gets increased.

**Table -2:** Summary for results under different conditions

| Sag Type | h | Current Peak | Torque Peak | Speed Loss |
|---|---|---|---|---|
| A | 0.1 | 5.21 | 4.05 | 25 |
| | 0.5 | 3.15 | 2.73 | 8.7 |
| | 0.8 | 1.66 | 2.33 | 3.43 |
| B | 0.1 | 3.67 | 2.65 | 6.68 |
| | 0.5 | 2.2 | 2.35 | 3.7 |
| | 0.8 | 1.56 | 1.95 | 2.5 |
| C | 0.1 | 4.72 | 3.95 | 14.76 |
| | 0.5 | 2.95 | 2.58 | 5.52 |
| | 0.8 | 1.86 | 2.25 | 3.3 |
| D | 0.1 | 5.12 | 3.95 | 14.76 |
| | 0.5 | 2.45 | 2.58 | 5.52 |
| | 0.8 | 1.17 | 2.25 | 3.3 |
| E | 0.1 | 4.18 | 2.97 | 15.4 |
| | 0.5 | 2.77 | 1.85 | 4.96 |
| | 0.8 | 1.41 | 1.37 | 2.04 |
| F | 0.1 | 4.23 | 2.97 | 15.4 |
| | 0.5 | 2.71 | 1.85 | 4.96 |
| | 0.8 | 1.18 | 1.37 | 2.04 |
| G | 0.1 | 4.20 | 2.97 | 15.4 |
| | 0.5 | 2.66 | 1.85 | 4.96 |
| | 0.8 | 1.02 | 1.37 | 2.04 |

## 4. CONCLUSION

The classification for different types of sag has been done and the effect of different sag initiation angle on induction motor performance in terms of torque peak value, current peak value and speed loss of machine has been studied. It can be concluded that in case of sag Type A there is no effect of initiation angle on performance of machine but for sag Type B and Type D maximum torque peak, current peak and speed loss in performance of machine can be observed for initiation angle of $90^0$ and $0^0$ for sag Type C and Type E respectively. It has been observed that on the increment of the value of sag magnitude, the value of other parameters of machine under consideration also gets increased. It can also be observed that the effect of sag Type A on the performance of machine is more as compared to other sag Types.

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