Abstract—The starting period of induction motor is characterized with high starting current and the bus on which the motor is feeding from experiences voltage dip, this causes some problems to loads connected to that particular bus. Different techniques are used to either reduce the motor inrush starting current or the bus voltage dip or both. Four different methods are considered in this paper using ETAP simulations and the mode of comparison are the starting current; reductions in bus voltage dip, starting torque, and energy savings. However, the paper did not state that any method is preferred over the other; it only points out the characteristics of the various methods, the user is to make his starting aid choice based on what he wants to achieve.

Index Terms—Aid; Comparison; Motor Starting.

I. INTRODUCTION

When electric motors are switched-on and introduced into a power system, the starting motor provides a low impedance path to the system; thus, a relatively high current from the power system flows to this low impedance path (starting motor circuit). This causes a sharp fall in supply current to other neighboring loads resulting in voltage drop in the system; (noticeable with lighting loads). This high inrush current is about six times the rated current [1]. This causes serious problems to these neighboring loads if not well managed. Many methods have been provided for reducing either the motor starting current or the voltage dip noticed during the inrush mode of the motor. This paper shall investigate the starting behavior of induction motors and the various methods of reducing the starting current and/or reducing bus voltage dip; these are the start-aided devices. A valuable comparison will be drawn between these devices; however, the comparison shall not include financial evaluation.

II. DIFFERENT START-AIDED DEVICES

For simplicity, consider a 50hp, 480V, 3 phase induction motor connected as shown in fig. 1 to a power grid with neighboring loads; with the line already loaded with the neighboring load, the induction motor was switched on.

Published on July 4, 2017.

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DOI: http://dx.doi.org/10.24018/ejers.2017.2.7.348
III. USING VFDs

VFD is an electronic electric motor starting aid devices (commonly applied to pumps, air handlers, etc.). It functions by power electronic principles in varying the frequency of the input power to the motor thereby controlling the motor speed. This gives reduced motor starting current, reduction in thermal and mechanical stresses on motor and belts during starting, etc. Consider that the motor shown Fig. 1 is now fed power through a VFD of 50hp with a control scheme shown in Fig. 4.
The control scheme is such that the VFD has a voltage per percentage frequency of 692V/%Hz (\textit{from } 415 \times \frac{100}{60}) initially has a % frequency of 0%, at the 2\textsuperscript{nd} second, % frequency gets to 40% (24Hz) by a ramp control mechanism, at the 3\textsuperscript{rd} second, the VFD attains its 100% frequency by a ramp control. An 8 seconds simulation time in ETAP gives the corresponding waveforms as shown in Fig 5 (a) to (f).

When powered with the VFD, the simulation in ETAP shows that the motor do not consume or demand any reactive power from the line. This zero reactive power demand from the line is partly responsible for the bus voltage to be almost constant from the motor’s starting stage to its steady stage.

IV. USING CAPACITOR STARTING

The use of capacitors as starting aids to electrical motors are aimed at reducing the voltage dip experienced by neighboring loads during the in-rush moment of these electrical motors by connecting them to either the motor bus or the motor terminals [2]; this is because these capacitors generate reactive power. They are known as capacitor banks or reactive power banks. One major merit of this starting aid method is its ability to improve power factor of electrical machines when connected in parallel to the electrical machines [3].

The rating of the capacitor bank used should at least be equal to the maximum reactive power that the machine takes in its in-rush moment. From Fig. 3(c), a reactive power demand of 190kVAr was demanded by the machine in the in-rush moment and 20kVAr was demanded in the steady
The simulation when the 200kVar is connected in parallel to the motor shows identical characteristics of the motor under study, it only differs in the bus voltage time characteristic as shown in Fig. 6.

Fig. 6: (a) % nominal bus voltage – time, (b) % full load current – time, (c) % slip – time

A reduction in magnitude of bus voltage dip, an increase in the line current and a lower rate of decrease of % slip resulted as compared to the normal case.

V. USING AUTO-TRANSFORMER

The method of using Auto-Transformer to start induction motor is very common in the industry and it is relatively cheap and efficient. To achieve this, a changeover switch and a UPS (interruptible power unit) are required. The tapings available on the auto-transformer varies from 0 % to 100 % of rated voltage, from which 65% was used; when speed reaches 95% of rated speed the switch is changed from the auto-transformer tapings to the mains i.e. to the full rated voltage [4]; the control scheme of the autotransformer is shown in Fig. 7.

When the induction motor starting process is aided by an auto-transformer, its behaviors are as shown in Fig 8.
It is observed that the waveforms of the various quantities differ from when the motor started without any starting aid.

VI. USING STAR-DELTA STARTER

In this method, the motor is fed from a star-delta system during starting. Using this starting method also requires a changeover unit and a UPS. This method has an advantage of being very cheap and easy to use. However, in some cases, it develops harmonics.

The arrangement reduces the starting line voltage by $\sqrt{3}$ thereby reducing the bus voltage dip and also gives a reduction of the starting torque [5], [6].

Running the simulation with a star-delta starter, the results obtained shows similar characteristics when on normal starting; the difference is a slightly higher starting current but a reduction in bus voltage dip.

VII. RESULT AND COMPARISON

The unaided starting case of the motor shows that the motor has a starting and steady state current of 472% of FLC (full load current) and 95% of FLC respectively. Maximum and minimum starting motor and load torques are 84% and 6% respectively and their steady state values are 92%. The minimum bus voltage at (1st second) and steady values are 89% and 96% of nominal bus voltage respectively. Total energy consumed is the sum of that consume during inrush and steady state. Energy demand:

$$E_d = \sum_{i=1}^{n} [P_{ti} \times t_i]$$

$$E_d = \text{Energy demand}$$
$$P_{ti} = \text{Power consumed at } t_i \text{ second}$$
$$t_i = i^{th} \text{ second}$$
$$E_d = 320\text{kWs} + 160\text{kWs}$$

The results obtained by using the starting aid are compared in the Table I.
TABLE I: INDUCTION MOTOR STARTING AID COMPARISON

<table>
<thead>
<tr>
<th>Starting/steady state current</th>
<th>VFD (with the setting used)</th>
<th>RBP</th>
<th>VA</th>
<th>Auto Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor starts at 1st second with 9% of FLC and rose to 128% at the 5th second of simulation; the current then falls to a steady state value of about 89% of FLC.</td>
<td>Motor starts at 1st second with 528% of FLC and decreases until it attains a steady state current of 102% of FLC at the 4th second. The wave shape of the motor terminal current is similar to the unaided case of the motor.</td>
<td>The motor starts at the 1st second with 179% of FLC and sharply rise to 528% at 2nd second, it then decreases slowly until attaining a steady state value of 102%. Wave form is also similar to the unaided case of the motor starting.</td>
<td>Motor starts with a starting current of 226% of FLC at the 1st second and decreases until attaining a steady state current of 177%</td>
<td></td>
</tr>
</tbody>
</table>

Bus voltage dip

| Bus voltage at 1st second was 99.72% of NBV (nominal bus voltage) corresponding to a maximum dip of 0.28% of NBV. A steady nominal bus voltage of 99.61% was attained at the 5th second. | Bus voltage at 1st second of the motor starting is 97.64% of NBV. This corresponds to 2.36% bus voltage dip. When the motor attains steady state, bus voltage was 99.4% of NBV. | Bus voltage at 1st second of the motor starting is 99.02% of NBV, it further decrease to 98.26% of NBV at the 3rd second. This corresponds to a maximum of 1.74% bus voltage dip. When the motor attains steady state, bus voltage was 99.4% of NBV. | Bus voltage at 1st second of the motor starting is 98.83% of NBV. This corresponds to 1.17% bus voltage dip. When the motor attains steady state, bus voltage is about 99.02% of NBV. |

Torque

| Motor and load torques of 10% and 10% respectively at the 1st second of simulation was recorded. The motor torque sharply rises to 53% and then decreases to 13% at the 2.68 second mark. From there, increases again until attaining a steady value of 93%. The load torque decrease from 10% to 3% at the 1.88 second mark before rising gradually until it attain its steady value of 93%. | It has a starting motor and load torques of 93% and 93% respectively, the load torque kept increasing until it steady state value of 91.47% was attained. The motor torque decreases from its starting 93% to a minimum of 1.2% at 2nd second, it then increases to a maximum of 160% at 3.5 second before attaining steady state torque of 91.47%. | Starting motor and load torques are 32% and 10% respectively at 1st second. This increases to maximum of 102% and 62% respectively before decreasing and attaining a steady torque of 91.47% for both motor and load. | Starting motor and load torques are 40% and 10% respectively. They decrease and increase respectively at different rate be attaining a constant torque of 34%. |

Energy savings

| A total of 280kWs of energy was consumed in the 4 seconds inrush period. Hence, a total of 40kWs was saved. | A total of 260kWs of energy was consumed in the 4 seconds inrush. Hence, a total of 60kWs was saved. | No remarkable savings was noticed. | A total of 110kWs of energy was consumed in the 4 seconds inrush period. Hence, a total of 210kWs was saved. |

Finalization:

Please note that in all starting aided cases, the power consume in the steady state is the same.

VIII. CONCLUSION

Table II shows the summary of the various starting aid methods.

TABLE II: SUMMARY OF VARIOUS STARTING METHODS

<table>
<thead>
<tr>
<th>S/N</th>
<th>Starting aid</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>VDF</td>
<td>Highly reduced starting current. Highly reduced bus voltage dip. Reduced starting motor torque. Low energy savings.</td>
</tr>
<tr>
<td>3.</td>
<td>Auto transformer</td>
<td>Reduced starting current. Reduced bus voltage dip. Reduced starting motor torques. High energy savings.</td>
</tr>
</tbody>
</table>

IX. ACKNOWLEDGMENT

We would like to thank the laboratory technologist at Michael Okpara university of Agriculture Umudike electrical machines laboratory for the technical assistance they gave to us during the course of preparing this paper.

X. REFERENCES


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DOI: http://dx.doi.org/10.24018/ejers.2017.2.7.348
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