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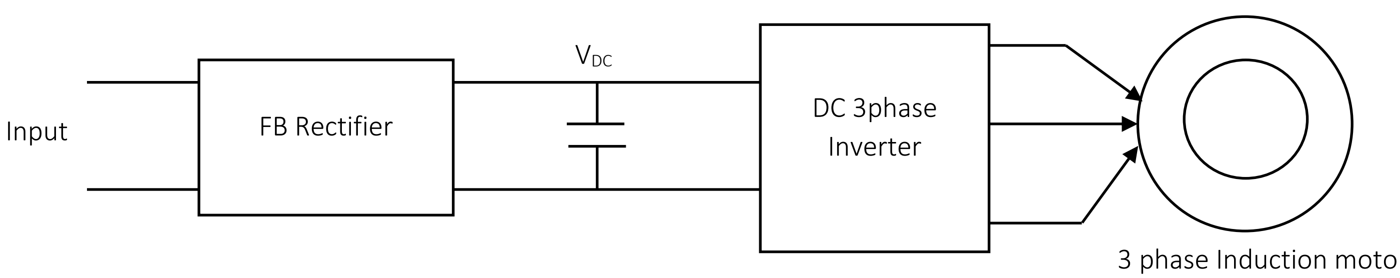
# DYNAMIC RESPONSE STUDIES ON V/f CONTROLLED INDUCTION MOTOR DRIVE

## OBJECTIVE

- To study various aspects of steady-state performance by SeimensV20 V/f drive on a three-phase induction motor
- To evaluate the dominant speed time constant under different steady-state V/f operating points of the drive

## OPERATION AND BEHAVIOR OF INDUCTION MOTOR




The rotational speed of an induction motor can be changed in a stepless way by changing the frequency of the supply voltage

$$V = E1 = 2\pi \times k\,1 \times N\,1 \times f \times \varphi$$

where,

E1 = stator induced emf/phase

kw1 = stator winding factor

Nph1 = stator series turn/phase

$\phi r$ = resultant air-gap flux/pole

And, in order to avoid saturation in stator and rotor which would cause a sharp increase in magnetization current, the flux $\phi r$ must be kept constant as f is varied.

Thus, when f is varied, V must also be varied such that (V/ f) remains constant.

## STEADY-STATE PERFORMANCE

For the steady state performance analysis, V, I DC link voltage and Speed are tabulated as shown below for the steady state behavior across different frequencies. Since the flux is to be kept constant by keeping V/f constant for optimal performance, the speed would be directly proportional to frequency ideally.

| f | V | I | DC link | Speed(rpm) |
|---|---|---|---|---|
| 0.5 | 7 | 0.4 | 330 | 15 |
| 1 | 8 | 0.4 | 333 | 30 |
| 5 | 13 | 0.44 | 332 | 150 |
| 10 | 20 | 0.4 | 332 | 301 |
| 15 | 32 | 0.44 | 331 | 451 |
| 20 | 48 | 0.51 | 331 | 602 |
| 25 | 66 | 0.56 | 330 | 753 |
| 30 | 86 | 0.63 | 330 | 904 |
| 35 | 108 | 0.68 | 330 | 1054 |
| 40 | 131 | 0.73 | 330 | 1205 |
| 45 | 156 | 0.80 | 328 | 1355 |
| 50 | 182 | 0.85 | 330 | 1506 |

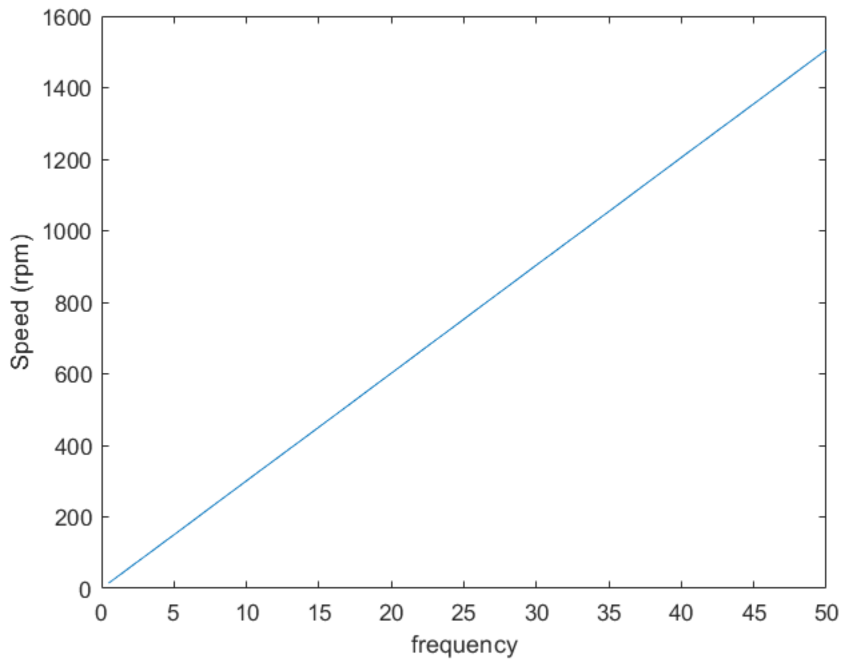
However, due to the non-linearities present in the system, the behavior observed is quite different from the theoretical predictions.

Initially the first and foremost non linearity is due to the knee point which is related to a highly nonlinear behavior of flux and magnetizing current. As soon as the operating point changes, the linearized model of 3phase induction motor changes. Practical reasons for this could include effects ranging from electriomagnetic and inertial effects in practical systems to design approximations assumed in the model.

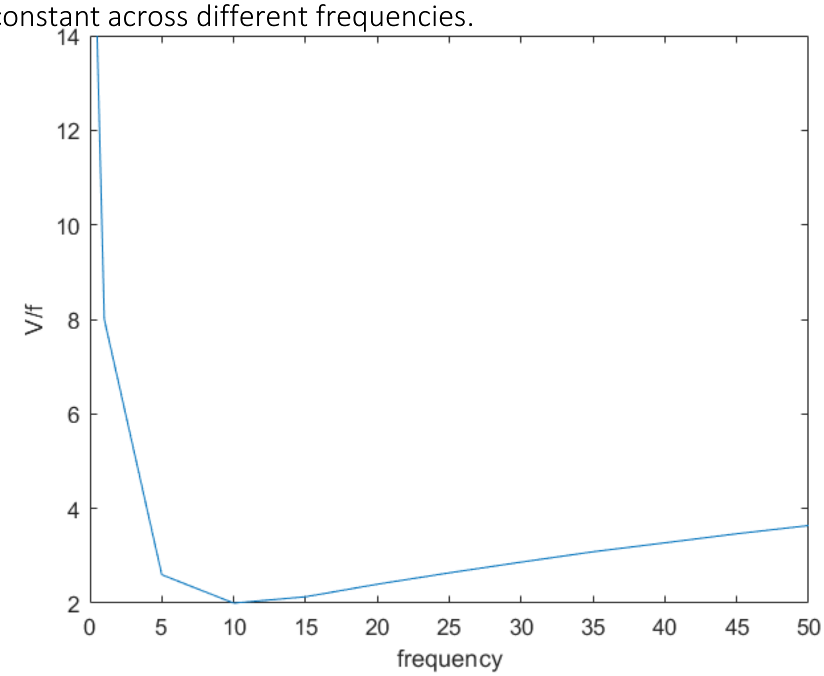
Apart from that, the second non linearity is associated to the frequency dependency for the terminal voltage characteristics of the drive.

And third non linearity can be seen in the $V_{DC}$ which should have been constant.

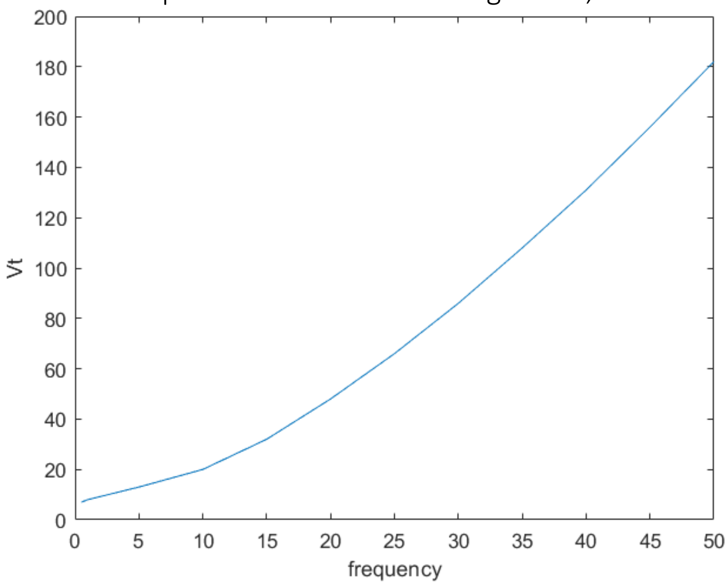
All these non linearities heavily affect the system thereby showing a dominant non linear behavior in the output. Given below is the speed vs supply frequency for the induction motor which although shows a straight line (due to a really well designed controller in effect) but when we look at other parameters like DC link voltage, V/f or I, the non linearities are clearly visualised.

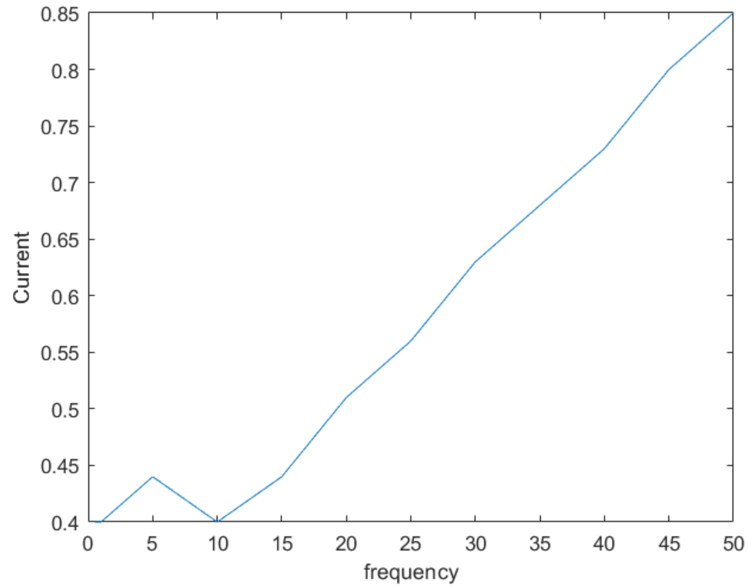



The plot shown below which clearly shows that the operating point of the induction drive is not stable at all i.e., V/f is not constant across different frequencies.



And as shown below, the terminal voltage is not observed to be strictly proportional to the frequency. For lower frequencies, terminal voltage is unexpectedly higher. This is because a voltage boost is required to compensate for stator winding losses, which are clearly non linearities.



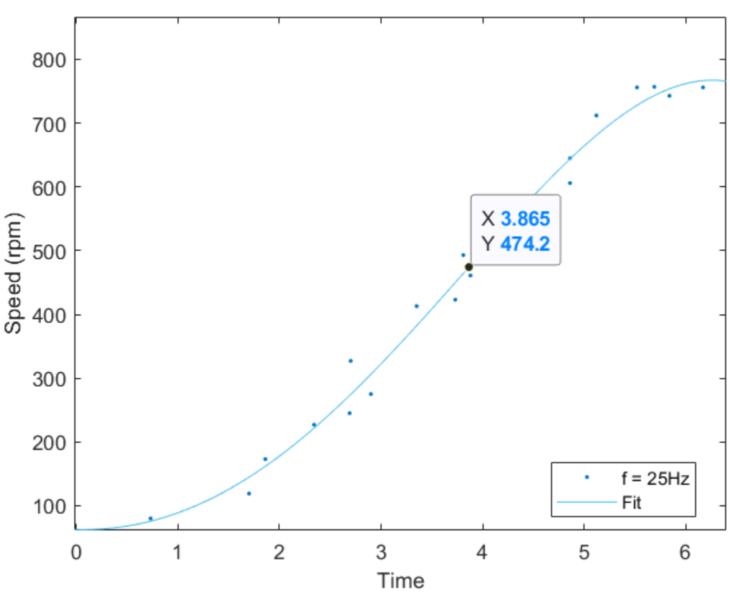

The inverter current is found to be increasing linearly as well, although should have been steady as the motor is not loaded, and a few deviations are witnessed in the DC link voltage but remains close to 330V for majority of operations.

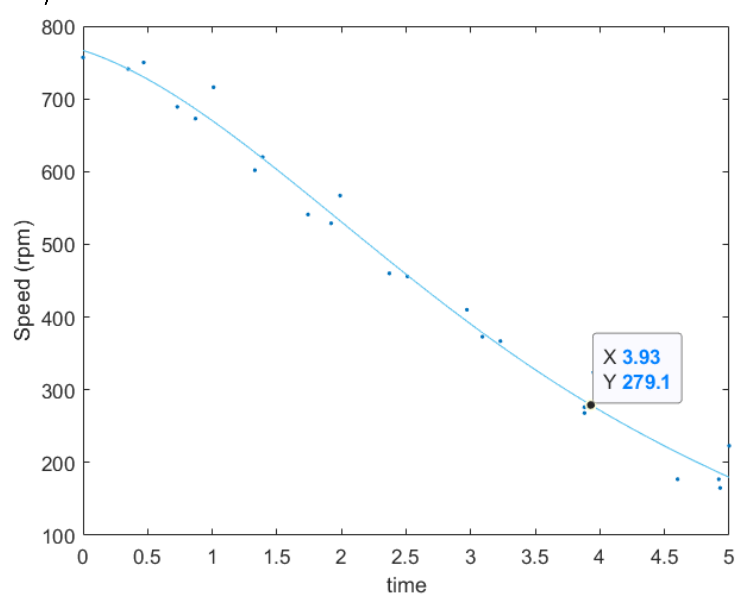
## DOMINANT SPEED TIME CONSTANT

Assume that we are operating the induction drive at a constant {V, f}, it is important to know the time response of the induction drive and time constant associated for reaching to steady state values.

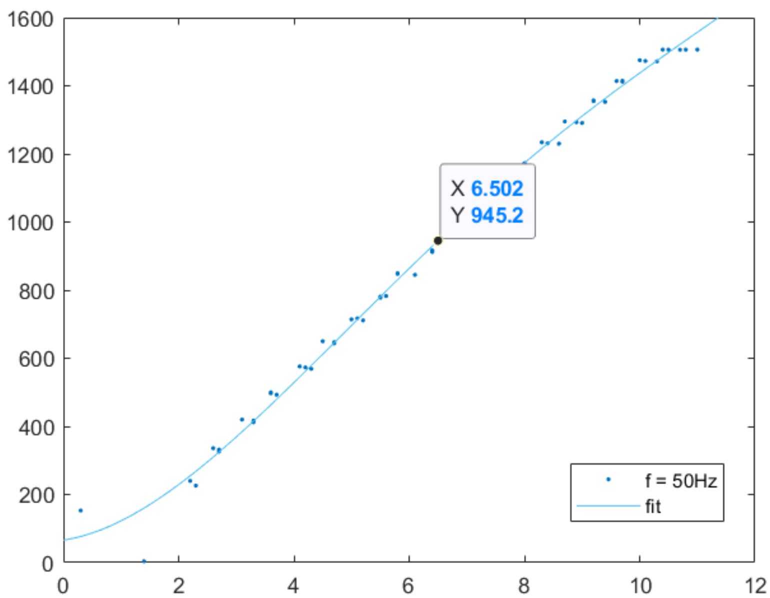
For the same, the behavior of speed dynamics for different frequencies was recorded. For lower frequencies, the system remained closer to first order system however as the frequency goes higher, non linear effects become more and more dominant. The behavior observed for counter clockwise direction of rotation was found to be similar without any significant changes.

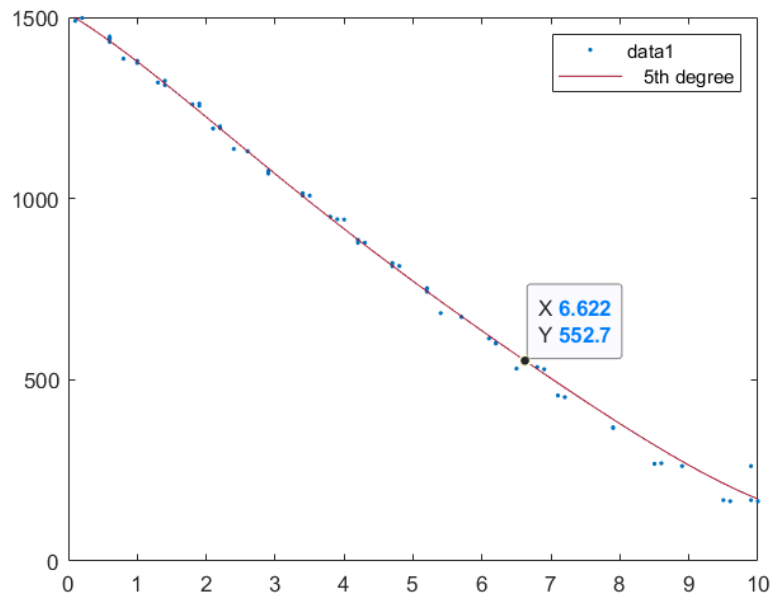
Shown below are the speed dynamics for supply frequency of 25Hz.



And shown below are the dynamics for 50Hz. The behavior gets closer to a straight line as frequency is increased which also highlights that the controller designed for the induction motor works impressingly well. And with these increased non linearities, the analysis for it becomes further difficult.




| frequency | Time Constant (Rise) | Time Constant (Fall) |
|---|---|---|
| 25 | 3.865 | 3.93 |
| 40 | 5.11 | 5.605 |
| 50 | 6.502 | 6.662 |

The non-linearity offered by change of operating point, DC Link voltage change as well as in variation of Vt control heavily affects the speed dynamics. The non-linearities as mentioned earlier related to the effects include lag, slow response and variable time constant which makes the precision control for the induction motor really poor.

While calculating the time constant the rise time and fall time take different values even for the same frequency and thus clearly points out towards the collective non-linearity of the system.