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Latest insights – Variable frequency drives and borehole pumps

One of the topics getting the most attention in Franklin Electric's "FranklinTECH" seminars is the chapter treating variable speed operation of borehole pumps.

After 'conquering" almost every other branch of the industry, variable frequency drives have gradually made their way into submersible pumping applications. Yet, when applying VFDs to this specific environment, it is critical system designers and operators understand the physics behind the method of controlling speed and take the necessary precautions to ensure satisfactory service life for both motor and pump.

> *So, what is a standard variable frequency drive and how does it control motor/pump speed?*

Today, virtually all industrial drives are of the "voltage-source" type which means they will convert incoming AC grid voltage to DC and "store" this battery-type voltage in an array of capacitors called DC link.
Then, an array of "valves" or "switches" will chop this DC voltage following a predetermined pattern to generate a high speed train of voltage impulses at the drive's output.

Simply put, each outgoing phase is alternately connected to the "+" and "-" terminal of the DC link or left "idle". How often in a second this switching takes place is given by the so-called "carrier frequency" that ranges between some kHz to some tens of kHz.

The figure 1 depicts the block diagram of a standard DC-link VFD with associated voltage graphs:

It is important to note the output signal of these drives is not the sinusoidal AC voltage that induction motors have been built to work with. As depicted, the voltage that can be measured at the drive's output is a train of impulses that mimic a sinewave.

Worse, because of the high switching frequency of today's drives, long cables at the VFD output generate transmission line effects **that effectively double up the DC link voltage** when it hits the motor terminal.

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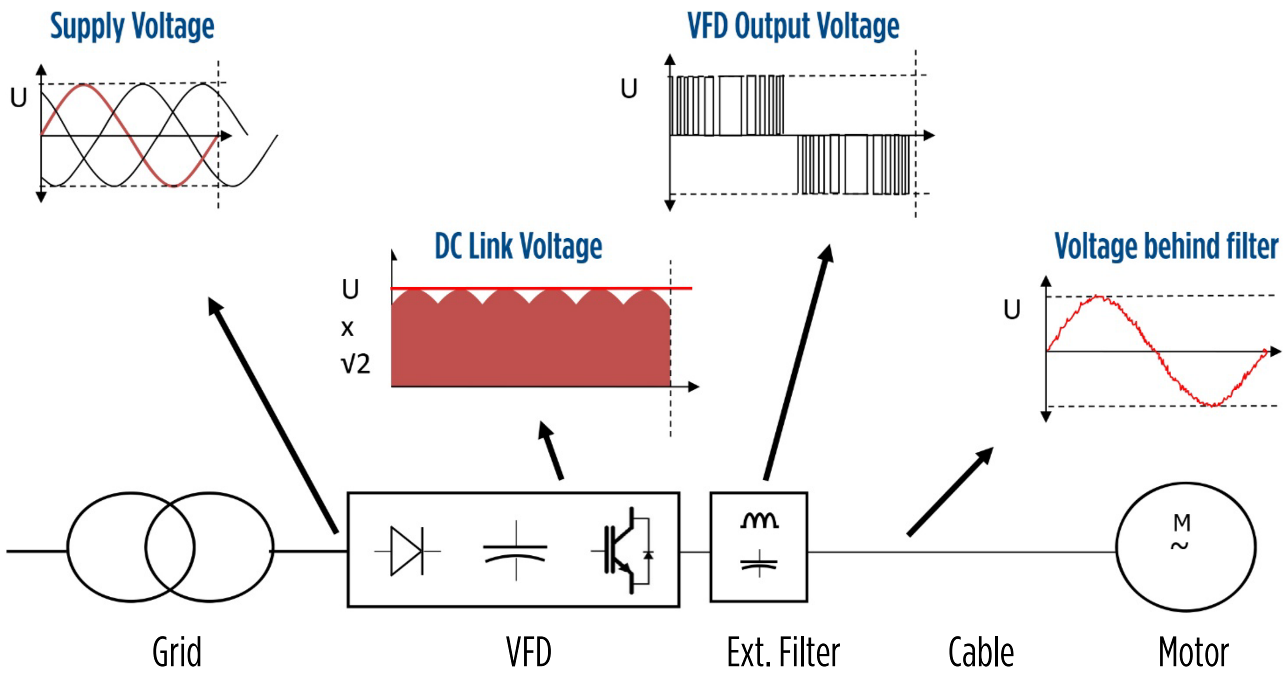
Fig. 1:



While the above is all pretty technical, what we have to walk away with is a good formula for calculating the voltage stress at the motor terminals starting from the VFD input (grid) voltage:

$$V_{SUPPLY} \times 1.4 \times 2 = V_{MOTOR}$$

For a standard 400 V grid, the motor terminals will see 2.8 x 400 V = **1120 V voltage peaks** between phases **and very similar voltages to ground potential.**

Standard induction motors have been designed to operate grid-fed at nameplate sinusoidal AC voltage. Their insulation systems will suffer from permanent high dv/dt and voltage peaks generated by VFDs.

There are several solutions available to increase service life of submersible motors when supplied by voltage-source VFDs:

> *Always install output filters!*

These should be sized in accordance with the VFD manufacturer indications and should limit voltage peaks at the motor terminals to 1000 Vpp both line-to-line and line-to-ground. Voltage rise time should be less than 500 V/µs.

Important facts about output filters

- Output filters can be ordered in a variety of configurations to match different applications. As a rule of thumb, output reactors and dv/dt filters are less expensive but also less effective and should be used up to ~120 m of total output lead length.

> *Sine wave filters are the best option*

  and are recommended whenever longer cables are needed.

- Output filters should be matched to the drive's carrier frequency to avoid resonance and overheating

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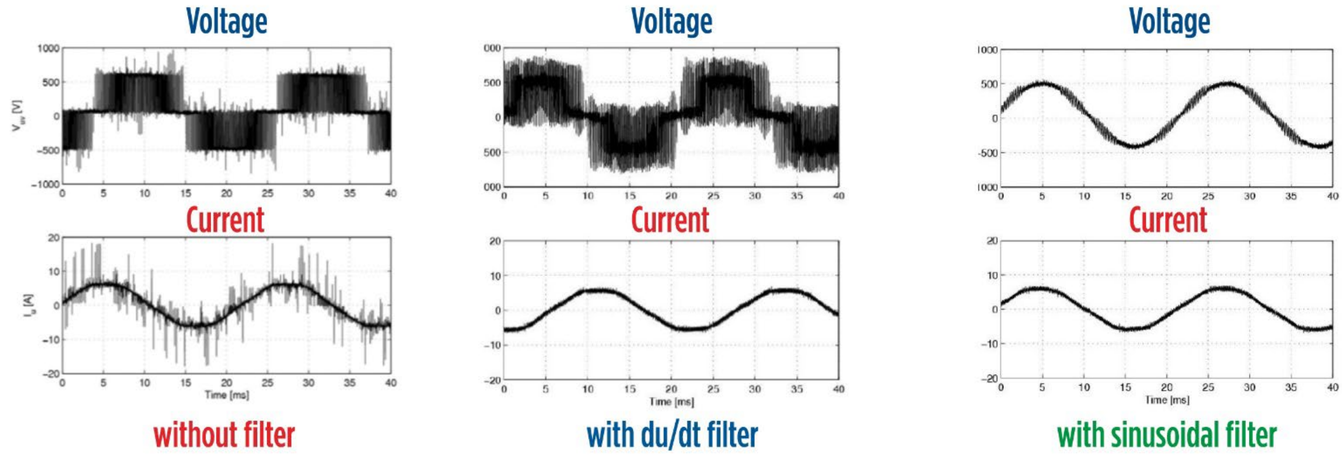
Fig. 2: Typical voltage outputs for different filter types:

OUTPUT FILTER



- Last but not least, standard filters will only decrease line-to-line voltages and voltage rise times.

> ***For best protection, 4-pole filters acting also on the line-to-ground voltage peaks are recommended.***

Drive-Tech MINI

- Grid voltage is the base for calculating voltage peaks at motor terminals. Even is the VFD settings allow motor nameplate voltage setting, ***280 % of grid voltage*** will always hit the motor insulating system. Standard motors should therefore be used up to max. 460 V / 60 Hz VFD input voltage.

- For Franklin Electric Rewindable Submersible motors, we recommend ***choosing PE2/PA winding wire*** when operated by VFD.

- For higher drive input voltage, special motor designs with increased insulation material strength are available upon request.

TRAININGS

German: 12 – 13 November 2019
English: 19 - 20 November 2019

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