Active Front End Converter in Common DC Bus Multidrive Application

Nebojsa Mitrovic[1], Vojkan Kostic[2], Milutin Petronijevic[3] and Bojan Bankovic[4]

Abstract **– In this paper, methods of energy recovery for AC adjustable speed drive in braking mode are presented. The analysis includes different front end converter topologies in terms of energy regeneration capabilities. Three solutions are found in practice: diode rectifier with braking modul, line-commutated rectifier-regenerative feedback unit and self-commutated pulsed rectifier-regenerative feedback unit. Results of practical application of the active front end unit on common dc bus are shown for the multimotor crane drives.**

Keywords **– Multi-motor drives, Active front end, Common DC bus, Crane drives.**

I. Introduction

Adjustable speed drives (ASD) in industrial applications are usually characterized by a power flow direction from the AC distribution system to the load. This is, for example, the case of an ASD operating in the motoring mode. In this instance, the active power flows from the DC side to the AC side of the inverter. However, there are an important number of applications in which the load may supply power to the system. When the rotating element of an AC motor turns faster than the AC drive's speed command, the motor begins to act as a generator and regenerates energy back into the DC bus of the drive. Moreover, this could be an transient condition as well a normal operating condition. This is known as the regenerative operating mode. For example, these regenerative conditions can occur when quickly decelerating a high inertia load (flywheel) and this can be considered as transient condition. The speed control of a load moving vertically downward (hoist) or declining conveyor in minning application can be considered as normal operating condition, [1]. If the drive cannot absorb this excess energy, the DC bus voltage will continue to climb until the drive trips on a high bus fault.

This paper presents the characteristics of the three most commonly used topology for the front end rectifier: diode rectifier with brakig modul, line commutated regenerative unit and pulse comtutated pulse regenerative unit. Finally, the paper addresses the main characteristics and performance of the crane drives with active front end rectifier on common DC bus.

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II. Regenerative Operating Mode in ASD

The typical pulse width modulated AC drive is not designed for regenerating power back into the three phase supply lines, so all energy absorbed from the motor goes into the capacitor bank, resulting in increased DC bus voltage inside the drive. When equipped with a standard duty braking module and resistor, the drive is capable of dissipating only short-term energy, typically a few seconds at a time. It is possible to specify a braking module and resistor to dissipate this energy continuously, by taking into consideration the maximum current capacity of the brake switch, the duty cycle and the resulting power rating of the resistor. In either case, energy dissipated in a braking resistor is energy wasted.

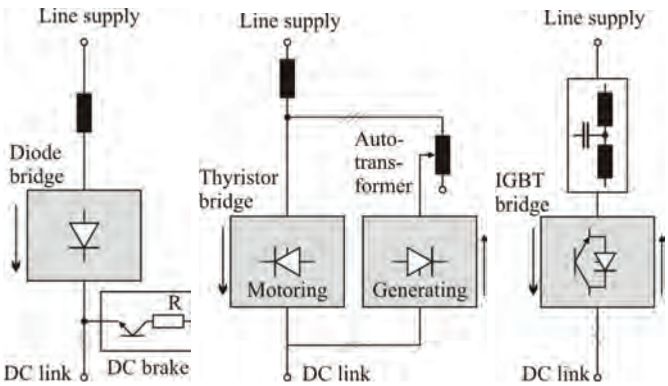

Fig.1. Front-end rectifier unit: a) Diode bridge with braking modul, b) Line-commutated rectifier-regenerative feedback unit, c) AFE-self-commutated pulsed rectifier-regenerative feedback unit

Besides the wasted energy during braking, there also is the disadvantage of not having any control over the DC link voltage. Also, the drives have to use large capacitor banks to "smooth" the DC link voltage. That's because the ripple frequency due to the rectifier tends to be relatively low and depends on the line frequency and number of diode bridge phases. For example, if the line frequency is three-phase 50 Hz, and if the system uses a three-phase diode bridge rectifier, then the ripple frequency will be 300 Hz.

A line-regenerative drive can improve on the diode rectifier front end by employing a 6-pulse SCR/thyristor bridge for rectification and another antiparallel thyristor bridge for regenerative feedback through a transformer. Such a system will allow power to flow back to the line (full four-quadrant operation), eliminating or greatly reducing the need for the brake resistors and improving system efficiency. This topology provides several advantages when compared to the diode bridge rectifier front end, including four quadrant operation and control over the DC link voltage. However, this approach has disadvantages such as the addition of the antiparallel thyristor bridge and the requirement for filter components due to the use of line-commutating devices. Another drawback is the need for expensive compensation equipment to maintain power quality of the regenerative feedback. The large size and weight of the system can pose a challenge in some applications, [2-4].

Replacing the SCR/thyristor converters with IGBT-based active converters, also known as active front ends (AFE), will provide all the advantages of a four-quadrant regenerative drive while eliminating harmonic currents and improving the power quality without the need for expensive compensation equipment. AFEs also improve system efficiency and dynamic behavior of the load, as well as eliminate the need for the antiparallel converter or brake resistors. The active converters also significantly reduce the size and weight of the system when compared to systems based on line-commutated devices. The ability to switch the devices independent of the line frequency, typically between 15 kHz and 20 kHz, makes the filtering components smaller, lighter and less expensive.

When there are multiple drives in one location the common DC bus system is usually the most efficient way to operate and can incorporate the energy savings and recover concepts that have been previously discussed. However, if there is a regenerative drive and motor section in the system it is ideally suited for maximizing energy recovery and cost savings. The reason is that losses are generated when power is converted from the AC supply to the DC bus or from the DC bus to the AC supply. For multiple standalone (compact) drives, the power must go through two or more AC to DC conversions and two DC to AC conversions.

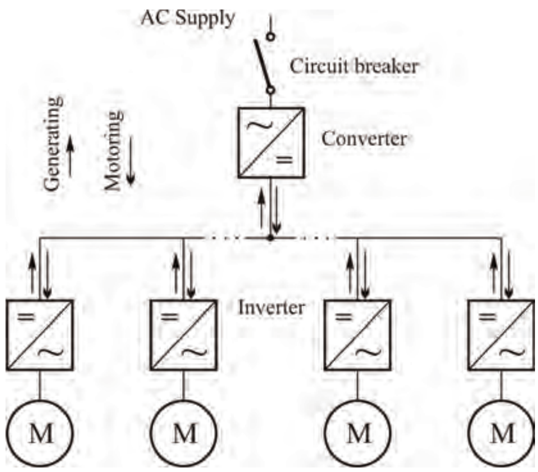

Fig 2. Common DC bus example

In a common DC bus configuration power only goes through one AC to DC conversion in the motoring direction, Fig.2. When an inverter section of the drive regenerates power to the DC bus, the power goes straight to another inverter, which is motoring via the common DC bus link, and does not have to travel through a converter at all. This method eliminates two conversion points where energy would be lost which increases efficiency by few percent for each regenerative section. The more sections there are which are regenerative, the more energy savings are accumulated. In addition, when a common bus solution is used with an AFE, it will have the ability to do power factor correction, which further increases the savings of a common bus system.

III. Case stady - Active Front End Converter in Multimotor Crane Drives

A. Torque and power requirements for crane drives

Speed control is an essential feature in crane drives. It is required for allowing soft starting and stopping of the travel motions for enabling its correct positioning of load. The torque and power that have to be delivered by the drive may be obtained from the torque versus speed characteristic from the load, [5,6].

If no wind influence has to be taken into account, the load characteristic is given in Fig.3a for travel motion. Apart from the zone around zero, the torque is constant. The available torque is used for accelerating the system.

The crane driver supplies the speed reference signal. For a travel in one direction, braking and reversing to full speed in other direction, the speed reference signal is given by top curve of Fig.3b. The torque reference signal is generated (second curve), leading to the machine actual speed. Myltiplying the actual and torque reference, yields the actual power (third curve). The peak power is found at the end of the acceleration period.

If wind forces are taken into consideration, the torque vs speed curve is shifted horizontally as shown in Fig.3c. The torque and speed reference remain the same, as well as the actual speed. However, the torque reference and the actual power differ, as shown on Fig.3d.

During acceleration, kinetic energy is stored in the system. To stop the crane, this energy must be absorbed by the drive. In the indoor situation, this energy is well known and only present for a short period of time. For outdoor applications, the wind forces may become very important. When travelling in the same direction as the wind, the wind drives the crane and a situation may occur, where a continuous electrical braking is required. The drive must be capable of handling this inverse power direction either by consuming the power in a resistor or preferably by feeding it back to the supply.

The hoist torque vs speed characteristic is shown in Fig.4a for an unloaded hook. The characteristic resembles the one for the travel motion. However, it is always asymmetric with respect to the vertical axis, due to the gravitation force. This asymmetry becomes more pronounced when the hook is loaded (Fig.4c). For both unloaded and loaded situation, the speed, torque and power are given in Fig.4b and Fig.4d. Again the amount of braking power is indicated. The worst braking case with a hoist motion, is when sinking a loaded hook. It should be noted that the weight of the hook may be considerable. The hook may be simple, or may consist of several parts to handle the load.

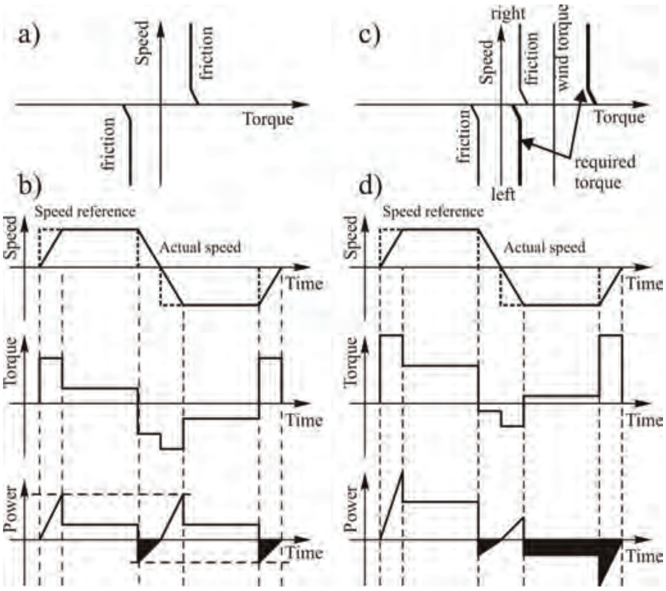

Fig. 3. Power and torque requirements for travel motion
a) and b) without wind influence, c) and d) with wind influence

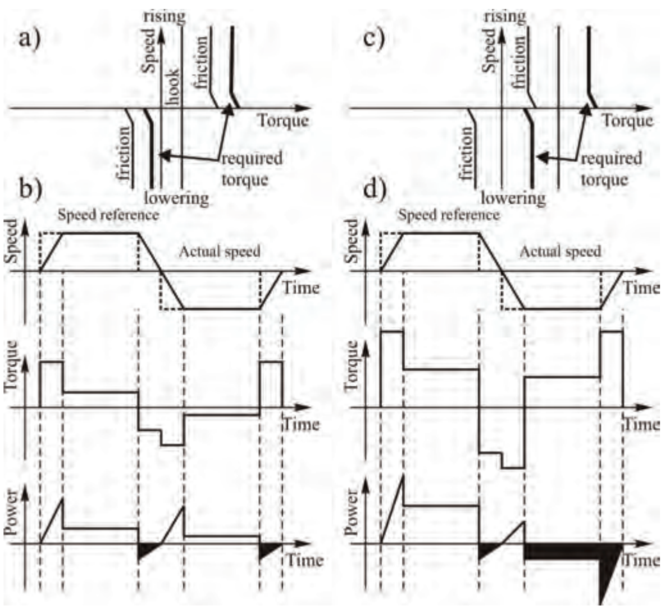

Fig. 4. Power and torque requirements for hoist
a) and b) without load, c and d) with load

A. Experimental results

The experimental behavior analysis of some drives is considered in a derrick crane, which serves for load handling i many industry branches. The main task in adjustable speed drives design is a safe, multi-axis movement that allows material handling throughout the working area, [7].

Using AFE rectifir/regenerative unit on common DC bus, five groups of invertor-motor combinations are supplied:
- hoist motion with 2x55 kW vector control inverter, the motor is a six pole, 2x45 kW,
- auxiliary hoist motion with a 55 kW vector control inverter, supplying a four pole, 45 kW motor,
- jib-boom motion with 2x55 kW vector control inverter, the motor is a six pole, 2x45 kW,
- travel motion with 3x7.5 kW vector control inverter , the motor , six pole 3x7.5 kW,
- auxiliary drives with 8x1.1 kW and motors (8x1.1 kW).

The rating of the AFE rectifir/regenerative unit output at cosφ=1 and 400 V supply voltage is 177 kW. This is far less than the sum of the ratings of the individual invertors, being 300 kW.

A number of experimental curves were recorded for the derrick crane. Fig.5 shows a hoist movement with the 30% of full load. Curve 1 gives the actual speed signal (reference speed signal is given at 100% from the crane driver joystick command). Curves 2, 3 and 4 shows the torque, power and rms motor current, respectively . After an acceleration period (ending at 5 sec), a constant torque is delivered. This transition in torque level coincides with reaching the prescribed speed. At 17.5 sec, the speed reference signal is made zero (stop command). The driving torque becomes zero and the system decelerates due to gravity. After 20 sec, zero speed is reached, and the drive has to deliver the torque required for holding the load before closing the mechanical brake. After that the same the same measurements were performed during lowering. Due to high friction losses, torque was required to start the decent, After short initial period, only the dynamic friction is present, yielding a small driving torque. After the acceleration, the power flow is reversed and the drive lowers the load at a constant speed. From 43 sec on, the system is braked with maximum torque, until standstill.

The same measurements were performed during lowering and hoist movement with the 30% of full load, Fig. 6. The reference speed was 25, 50, 75 and 100% of rated speed.

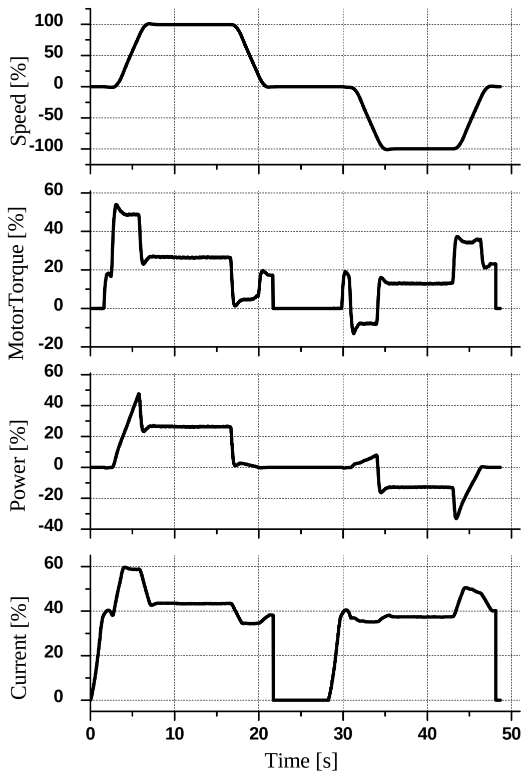

Fig.5. Measured pattern of the hoist motion

As on the Fig.5 actual speed, motor torque, power and rms current are shown. After that for jib-boom motion the same signal were record as shown on Fig.7. In both figure regenerative periods during the lowering, at any reference speed, can be seen.

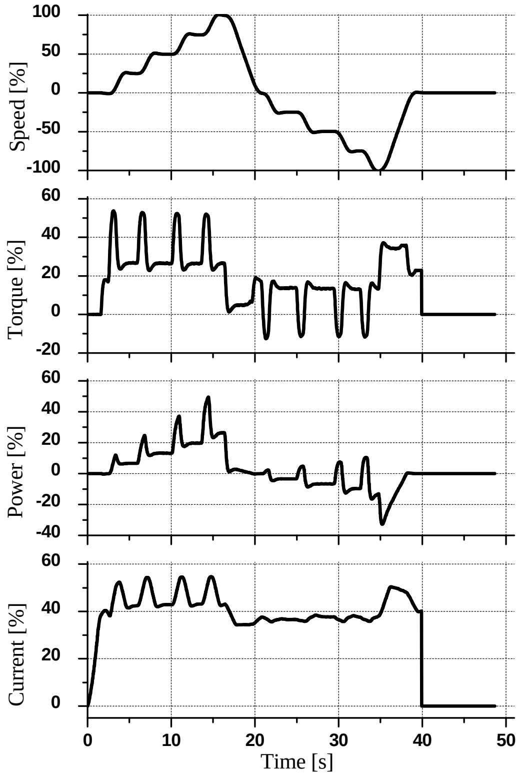

Fig.6. Measured pattern of the hoist motion at 25, 50, 75 and 100% of rated speed

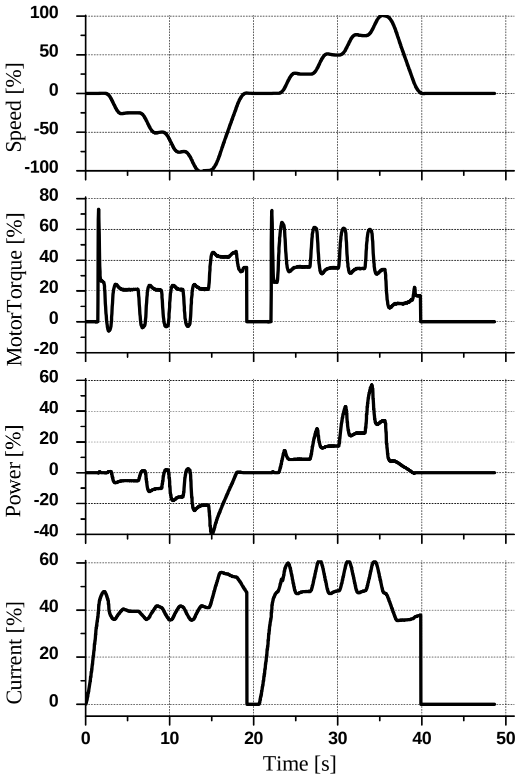

Fig.7. Measured pattern of the jib-boom motion at 25, 50, 75 and 100% of rated speed

From the Figs. 5 to 7, can be seen periods when the energy recovery occurs at the point of load lowering. It is very important to point out that the AFE topology allows for fully regenerative operation, which is quite important for crane application.

IV. CONCLUSION

This paper describes different drive technologies used in large power application. Each topology has advantages and disadvantages, especially from the power system point of view. The ability of handling regeneration and to suppress current harmonics is one of the basic features that must be included during the technical specification of such schemes. In multimotor drives the common DC bus system is usually the most efficient way to operate and can incorporate the energy savings and many other benefits such as: modular configuration, compact design, reduced installation costs, redundancy. In addition, common bus solution realised with Active Front End rectifier keeps the network current sinusoidal and a unity power factor by controlling the drive input to produce sinusoidal current without the harmonic components associated with conventional rectifiers.

Finally, it was shown that the use of AFE rectifiers in modern crane drives is a major technological advance and they produce an important improvement in the behavior of the drive system: higher power factor, reduced input current harmonics, and inherent regenerative operation.

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