Impact of Electric Drives in Efficient use of Electric Machines

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***Abstract*—This paper will illustrate the impact of electric drives in the efficiently use of electric machines. The Induction, Permanent magnet synchronous and Synchronous reluctance machines will be considered when making this study. The earlier and modern use of electric machines will be shown for comparison, the development of drives and their impacts on frequent standard revisions and on the drastically use of the new types of machines are shown. The energy control and management through drives control in cranes, elevators and escalators applications will be discussed and finally the conclusion will be made based on the highlighted figures.**

I. Introduction

The Electric Motor, is the electrical machine that converts electrical energy into mechanical energy. Since many years, electric motors have been seen playing the capital role in the industrial areas. It makes a great part in the equipments of industries. And looks to be the great part that consumes electric power. Taking into account last statement and considering that they transform electrical to mechanical energy; many researches have been conducted to make sure that the electrical energy supplied to the motor is more or less the same received from the motor in terms of mechanical energy. This reminds back the idea of efficiency. Through alot of researches, actually electric drives are ones of the results of those researches. The target of this work is to highlight the impact of electric drives in efficient use of electric machines.

The electric motors following their working principles, they have the common characteristics. The last ones are *Torque, Speed, Torque-Speed Characteristic, Starting, Power Handling, Maximum power and Corner Power*. This is illustrated in the fig.(1)

In additional to those characteristics we can also say *Cooling, gearing, Size, Efficiency, Cogging, Losses, Flux Leakage, Windage and Frictions and Power Factor*. Even if all of the characteristics have major roles, the strong focus will be taken on the efficiency.

II. Types of Electric Motor

Electric motor can be classified in different way, depending on the purpose of the use; but in the actual case, electric motors that will be considered are AC electric Motors, and based on their working principles and rotor construction. Due, the

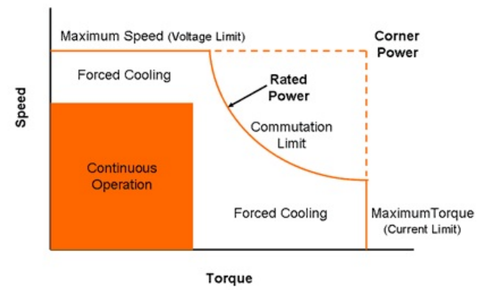

Fig. 1. Motor Characteristics [1]

Induction Motors, Permanent magnet Synchronous Motor and Synchronous Reluctance Motors.

A. Induction Motor

The *Induction Motor* or *Asynchronous Motor* is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the *Stator* winding. An induction motor can be *Wound rotor* or *Squirrel-Cage* type. The last one is the most widely used in industrial applications due to ruggedness and reliability.

B. Permanent magnet Synchronous Motor (PMSM)

This is the type of synchronous motor that uses *Permanent Magnets* rather than windings in the *rotor*. As the permanent magnet has a constant magnetic field, Electronic excitation control with integrated. *Power Converter* and *Rectifier, sensor* and *inverter* electronics is required for practical operation.

C. Synchronous Reluctance Motors (SynRM)

This is like the improved version of induction motor, the construction and appearance are almost the same; the only difference resides in the building of the *Rotor*. For the purpose of eliminating the *Rotor* losses.They have higher energy density as they are small in size. They are usually cold machines due to the fact that they don't have *rotor loses*.They also require drives in order to operate.

III. Electric Drives

Electrical Drives are referred to as in terms of their ability to efficiently convert energy from an *electrical power source to a mechanical load*; they are mostly for the main purpose of the mechanical loador process. The energy flows from electrical to mechanical i.e, motoring mode with power flow from the *power source* to the *mechanical load* via the *converter* and *machine*. The *drives* in some cases can allow energy to flow in reverse; in which case the *drive* often is configured bi-directional to allow energy flowing in both directions.

A. Different types of electrical Drives

Actually different types of electric drives are present including: Soft-Starter, Variables Speed Drives (VSD), and Variable-Frequency Drives (VFD).

IV. Motor efficiency

The efficiency of the electric motor is referred to as the ratio of the output mechanical power over the input electrical power, and it is always expressed in percentage. Even though the efficiency is defined and expressed in the same way in all of these machines, each machine has its own characteristics that can determine the efficiency, this section will discuss the those characteristics.

A. Induction Motor

When the popularity of the electrical drives was still low, *induction* and *synchronous* motors were only used at fixed and constant speed; the last case was like a requirement. The efficiency of these motors were evaluated based this functionality.

1) Efficiency of Induction Motor without Drive: The efficiency of*Induction Motor* is evaluated following the efficiency principle; considering the output to the input ratio:

$$\eta = \frac{P_{out}}{P_{in}} \tag{1}$$

It was only considered, taking into account input, loses and output power. All of these powers considered have different characteristics; the input power has electrical characteristics, while the output power has mechanical characteristics.

$$P_{out} = T\omega \tag{2}$$

With ω the rotational speed and T the torque. These two parameters will be varying from the dynamics to steady state characteristics of the motor.

From Fig.(2), The mechanical behavior of an Asynchronous motor is *almost linear* between no load and the rated load. The *maximum torque* produced by an *asynchronous motor* is between *two and three times its rated torque*. Unless the load can be externally accelerated during the start-up process, the *start-up torque* of the machine must *be higher* than the torque of the load at standstill. The relationship between motor torque and supplying voltage is *quadratic*, i.e if supply voltage is reduced to half the rated voltage, the motor torque is reduced to quarter of the rated torque. It can be seen from the Fig.(2), that

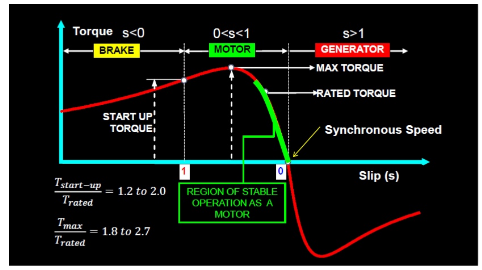

Fig. 2. Torque vs Speed [2]

the torque of *Asynchronous motor* changes with the changes in the *slip*. The last one also has an effect the mechanical angular speed.

$$\omega_m = (1 - s).\omega_s \tag{3}$$

From the eq.(3); the mechanical speed also is affected by the *slip*. Due the mechanical power is affected by this parameter. Due, it affects the efficiency.

2) Efficiency of Induction Motor with Drive: As it was discussed before, the *Asynchronous Motor* was used before at constant speed. Due, there were no control on the speed of the motor, mostly on its starting. The following methods were used: *Direct-on-line motor start and Star-Delta motor start*. The efficiency of this case was discussed in Fig.2. In the modern industrialization, the *Asynchronous motor* had to be used on different types of loads, where some of these loads are variable in time. So, the new technology proposed other types of devices that helps the *Asynchronous motor* to be suitable with the loads in case. They can even be used at different frequencies, as well as different speeds. Due, they can be controlled. The starting of these types of motors can also be controlled.

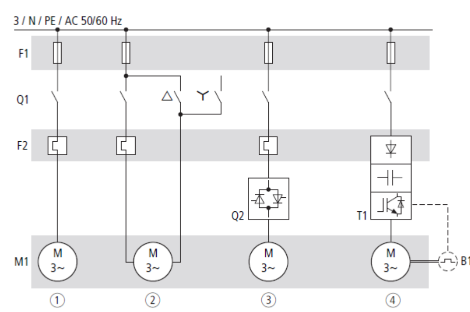

Fig. 3. Different control circuits [3]

3) Soft-Starter: In most of the cases, the *Direct-on-line* and staged *Star-Delta* start of the three-phase asynchronous motor is not the best solution, as high peak currents influence the electrical supply and torque surges subject the mechanical components of the machine or system to high level of stress. The *Soft-Starter* provides as solution; it enables a continuous and surge-free increase in torque and also offers the opportunity for a selective reduction in starting current. The motor voltage also increases within the adjustable starting time from a selected starting voltage to the rated motor voltage. The *Soft-Starter* can also control the run down of the drive by reduction of the voltage. The characteristic curve of the asynchronous motor applies only when the full main voltage U_{LN} is available . If a lower voltage is applied, there is a quadratic reduction in torque. When compared for instance to the *Start-Delta* start-up, the motor voltage is reduced 58%, $(-1/\sqrt{3})$ and the torque is reduced to about 33%, $(1/3)$. The difference between the load characteristic and torque characteristics of the motor, and accordingly the acceleration force, can be influenced by adjusting the motor voltage. The *Soft-Starter* should be preferred for all application with the start-up under load (load can not be connected after start-up) to the *Star-Delta* configuration. It is a good replacement for the *Star-Delta* configuration for the economic reasons and also for energy conservations reasons, particularly for high-power drives. The motor voltage in a soft starter is modified by a phase angle control of the sinusoidal half waves. For this purpose, two thyristors in the phase are connected in anti-parallel; one of them for the positive half wave and the other for the negative half wave.

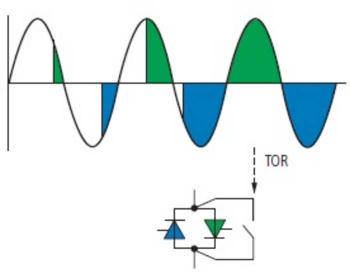

Fig. 4. Phase Angle control and Bypass contact [3]

After the set start time(t_{on}) has timed out, the thyristors are fully controlled. As the thyristors are only active during the acceleration phase, they can be bypassed by so-called bypass contacts during continuous operation. The losses on the Soft-Starter can be reduced by the considerably lower contact resistance of the mechanical switching contacts. The acceleration time of a drive a soft start results from the settings of the start voltage (U_{Start}) and the ramp time (t_{start}) for the linear increase up to full mains voltage (U_{LN}). The start voltage determines the breakaway torque of the motor. High start voltages and short ramp times correspond approximately to the direct-on-line start. In practice, the required breakaway torque (U_{start}) and then the short possible ramp time (t_{start}), are initially set for the required soft start. The set ramp time (t_{start}) is not the acceleration time of the drive. This is dependent on the load and the breakaway torque. The ramp time only controls the change in the voltage. In the process, the current rises to its maximum and the falls to the rated current,after the rated motor speed is achieved. The maximum current now sets to suit the drive (Motor plus load) and cannot be determined in advance. As a result, drives subject to high

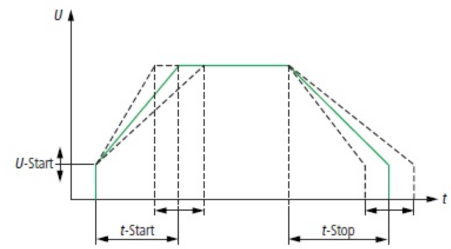

Fig. 5. Voltage curve in a Soft Starter [3]

loads in conjunction with long ramp times can lead to highly excessive thermal loading of the thyristors. If a determined current level is not to be exceeded, a *Soft-Starter* also enable a time-controlled reduction of the motor voltages and thus a controlled run down of the motors. The set stopping time

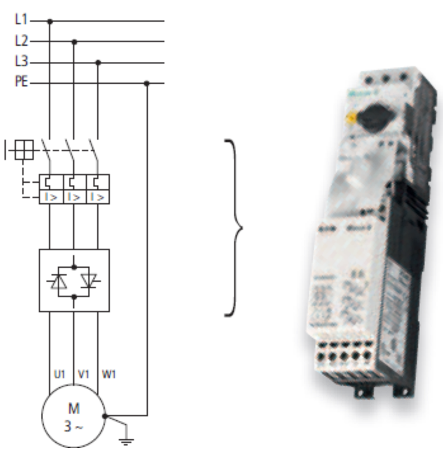

Fig. 6. Motor feeder, Soft-Starter [3]

(t_{stop}) must be longer than the load-dependent, free run down time of the machine. This process is also load-dependent just as the acceleration. The thyristors of the soft-starter are also subject to the same thermal stresses that were present during the start-up process.

4) Frequency Inverters: The frequency inverter is ultimately the best solution for continuous and stepless starting of the three-phase asynchronous motor. The adjustable current limitation prevents high current peaks in the electrical main supply and abrupt loads in the mechanical parts of the machine and systems. In addition to the smooth start-up, the frequency inverter also enables stepless speed (frequency) control of the three-phase asynchronous motor. Whereas motors connected directly to the main supply can only achieve the ideal operating conditions at steady state operation point. They can be utilized over the entire speed range with frequency control, for instance from 4V at 0.5 Hz to 400V at 50Hz. The constant ratio of voltage to frequency(U/f) guarantee independent operating points with rated-load torque. Even if compared to the lastly discussed solution, the *Frequency Inverter* looks to be expensive, with additional circuitry on the system and EMC issues; But during its operations at the very last, the soft motor start in addition to the *energy efficiency* and *process optimization* shows economic benefits. The last is especially true for some applications like: *Pumps* and *fans*. By the matching of rotation speed to the production process and the compensation for external interference, the frequency controlled drive unit is also reliable. Further more, other advantages are present for the frequency inverter; those include the higher speed stability with lower percentage of fluctuations in the load and the bidirectional rotational option. As the rotating field in the frequency inverter is generated electronically, a simple control command is all that is required to change the phase sequence and the direction of the motor rotation. The safe operation is assured without use of additional circuit; this is due to the electronic motor protection integrated into frequency inverter. Depending on the design method implemented, parameterized temperature models in the frequency inverter provide a higher level of motor heat protection. The frequency converter operates as a power converter in the main circuit of a motor feeder. Separated from the power of the DC link, the power converter draws active power through the rectifier from the main supply and supplies the motor with active; and reactive power required for motor operation is provided by the capacitor in the DC link. The frequency controlled drive behaves virtually like a resistive load ($\cos\varphi = 1$). And the figure below shows the

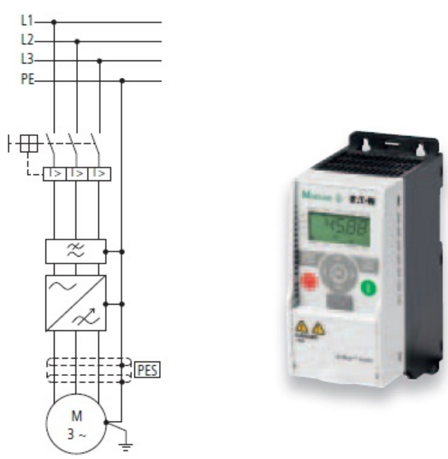

Fig. 7. Motor Feeder, Frequency Inverter [3]

two ends of the converting system.

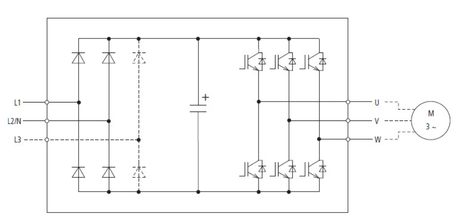

Fig. 8. Converting system [3]

B. *Permanent Magnet Synchronous Motors (PMSM)*

The Permanent-magnet sysnchronous machine (PMSM) drive has emerged as a top competitor for a full range of motion control application. The PMSM is actually widely used in machine tools, robotics, actuators, and is being considered in high power applications such as vehicular propulsion and industrial drives.This is due to the fact that the PMSM has *high efficiency, low torque ripple, superior dynamic performance* and *High power density*. These drives are often the best choice for high-performance applications and are expected to see expanded use as manufacturing cost decrease. The PMSM is a synchronous machine in a sens that it has a multiphase stator and stator electrical frequency is directly proportional to the rotor speed in the steady state. However, it differs from a traditional synchronous machine in that it has permanent magnets in place of the field winding and otherwise has no rotor conduction losses. These types of motors can not be connected directly to grid, it requires always a drive. The use of permanent magnets in the rotor facilitates efficiency, eliminates the need for slip rings, and eliminates the electrical rotor dynamics that complicate control (particularly vector control). The permanent magnet has the drawback of being costlier, but this issue can be resolved in long term by the fact that these machines are very efficient.

1) PMSM Construction overview: The PMSM consists of a multiphase stator and a rotor with permanent magnets. The machines can have either radially or axially oriented flux. The magnets can be either mounted on the rotor surface or buried in the rotor iron. The surface mounted variety presents a strong popularity due to: the simplicity of construction and control, and virtual absence of reluctance torque since the stator inductance is essentially independent of the rotor position. The interior magnet variety of rotors has significant reluctance torque due to position-variant stator inductance that complicates analysis and control issues. Other types of designs are also possible with particular performances and cost considerations. The motor construction aspects mostly

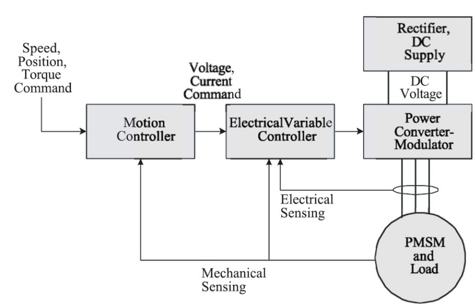

Fig. 9. Conceptual Drive system [4]

influence power converter design, these are like the shape of the back emf, the cogging torque, the magnetic saliency and the power requirements. A conceptual drive system shown in fig.(9) illustrates a speed, position, or torque command is input to the drive system. Based on the mechanical sensor the motion controller implements feedback control. The electrical control block converts its input commands into commands for the power converter/modulator block and sometimes utilizes feedback of voltage or current. The power converter block imposes the desired electrical signals onto the PMSM machine with the connected load. Through the control modeling of the drive construction, the current control can be used to chose the torque.

$$T_e = \frac{3}{2}\frac{P}{2}\lambda_m i_q + (L_d - L_q) i_d i_q \quad (4)$$

The torque of these type of machine is shown by equ. (4), can be controlled through controlling the current. As the output mechanical power is given by the product of the torque and speed. Then, the control can help to choose the useful torque, hence the better efficiency. From the figure (10), illustrate the

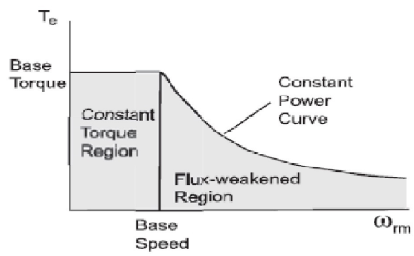

Fig. 10. Torque Speed Curve [4]

changes of the torque with the speed. Hence the change of output power. It gives the typical view of the points at which the power can be chose to maximize the machine efficiency. Due, the drive has a very important role to use efficiently these machines. To achieve the suitable control; it can be done by fixing the voltage or current in a PMSM drive to desired set point. With different control method that are actually applied, are used to ensure that the desired voltage or current is reached in the steady state

C. Synchronous Reluctance Motors (SynRM)

This is a type of *electric motor* that induces non-permanent magnet poles on the *ferromagnetic*rotor.Torque is generated through phenomenon of *magnetic reluctance*. They are machine with high power density at very low cost, this makes them ideal for many applications. They have an equal number of stator and rotor poles (Mostly 4 or 6 poles). The projections on the rotor are arranged to introduce internal flux "barrier", holes which direct the magnetic flux along the direct axis. As the rotor is operating at synchronous speed and there are no current conducting parts in the rotor, rotor losses are negligible. Once started at synchronous speed, the motor can operate with sinusoidal voltage. The speed control requires a *Variable-frequency drive (VFR)*

1) Operating Principle: In the *Synchronous Reluctance Motor*, the rotating field is produced in the air gap by supplying the stator winding with sinusoidal exciting currents. The torque is generated when the rotor attempts to align its most magnetically conductive axis, the d-axis, with the applied field, in order to minimize the reluctance in the magnetic circuit. The torque amplitude is directly proportional to the difference between the inductances on the d-and q-axes. Consequently, the greater this difference, the greater the torque production. There no rotor currents which means that it operates at low

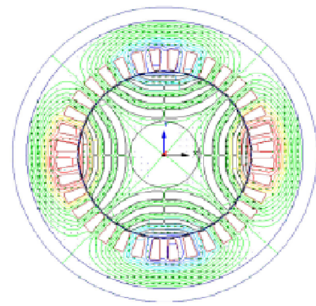

Fig. 11. Motor Cross-section structure [5]

temperature, increasing motor life-cycle and the reliability of the bearing system. The power converter is required for smooth operation with sinusoidal current.

2) SynRM Efficiency: The efficiency can be evaluated as usual taking into account the input and output power. It can be called back here that the output mechanical power is the product of te output load torque and mechanical speed. In the fig.12, we can see different values of efficiency as

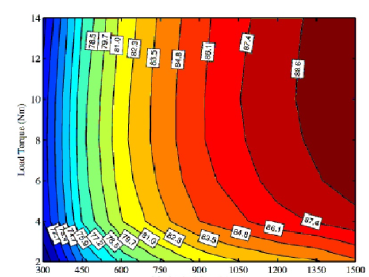

Fig. 12. SynRM Efficiency [5]

the load torque and Mechanical speed are changing during the operation. The efficiency of the machine alone without considering the converter, and at full load is 89.8%. From the fig.13, shows the efficiency of SynRM with a converter; it can be reminded here that these type of machines always work with converters. The total efficiency of this drive system at full load is 86.7%.

V. Motor Efficiency Classes

As part of a concerted effort worldwide to *reduce energy consumption*,CO_2 emission and the impact of industrial operations on the environment, various regulatory authorities in

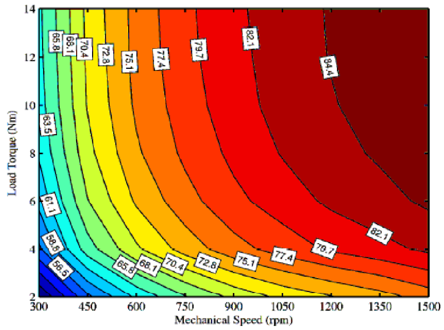

Fig. 13. SynRM and Converter Efficiency [5]

many countries have introduced or are planning legislation to encourage the manufacture and use of high efficiency motors.

The idea to improve the *electric motor* efficiency start with the realization of crisis in *Oil* and *Chernobyl Disaster*, the world found itself in need for more power and consequently more *Power Stations* have raised *Energy conservation* awareness.

A. Different Motor efficiency policies

The minimum efficiency level of electric motor was set as part of the *Energy Policy Act (EPAct)* by the US Congres in 1992. In 1998, the European Committee of Manufacturers of Electrical Machines and Power systems (CEMEP) issued a voluntary agreement of motor manufacturers of efficiency classification, with three efficiency classes [6]:

- Eff1 for High Efficiency
- Eff2 for Standard Efficiency
- Eff3 for Low Efficiency

The term "Premium Efficiency" was defined to be related to class of motor efficiency; due it was thought necessary to introduce this term associated with motors because of forthcoming legislation in EU, USA and other countries regarding the future mandatory use of premium-efficciency squirrel cage induction motors in defined equipment. Several statements have been made regarding motor use and the advantages of using premium-efficiency or high efficiency motor

1) USA Premium Efficiency Motor Program: The National Electrical Manufacturers Association (NEMA) actively participated in crafting major provisions on Energy Independent and Security Act of 2007 (EISA). A critical provision that NEMA focused on was increased motor efficiency levels. The Motor Generator section of NEMA joined forces with the American Council for Energy Efficiency Economy to draft and recommend new motor efficiency regulations covering both general purpose and some categories of definite and special purpose electrical motors. The Motor and Generator section of NEMA established the NEMA Premium Program for four main reasons [6]:

- Electric motors have a significant impact on the total energy operating cost for industrial, institutional and commercial buildings.
- Electric motors vary in terms of energy efficiency. The NEMA Premium program will assist purchasers identity higher efficient motors that will save them money and improve system reliability.
- NEMA Premium labeled electric motors will assist users to optimize motor systems efficiency in light of power supply and utility deregulation issues.
- NEMA Premium motors and optimized systems will reduce electrical consumption thereby reducing pollution associated with electrical power generation.

2) EU Premium Efficiency Motor approach: The EU enacted in June 2005, a directive on establishing a framework for setting *Eco-design* requirements (such as energy efficiency requirements) for all energy using products in the residential, tertiary and industrial sectors [6]. Coherent EU-wide rules for eco-design will ensure that disparities among national regulations do not become obstacles to intra-EU trade. The directive does not introduce directly binding requirements for specific products, but does not define conditions and criteria for setting requirements regarding environmentally relevant product characteristics (such as energy consumption) and allows them to be improved quickly and efficiently. It will establish the eco-design requirements. In principle, the directive applies to all energy using products and covers all energy sources.

3) Standardized Efficiency Classifications: IEC60034-30 specifies *Electric Efficiency* classes for single speed, three-phase, 50 Hz and 60 Hz, *cage-induction motors* that [6]:

- Have 2, 4, or 6 poles at 50 Hz.
- Have rated output power between 0.75 and 375 kW.
- Have rated voltage up to 1000V.
- Are rated on the basis of either duty type S1 (Continous duty) or S3 (intermittent duty)with a rated cyclic duration factor of 80% or higher.

The table V-A3 will show the IEC 60034-30 (2008) efficiency classes and comparable efficiency levels.

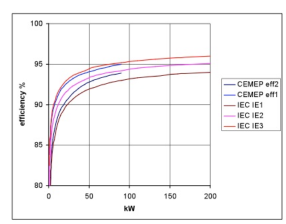

Fig. 14. Different efficiency levels [6]

For 60 Hz operation, the IE2 and IE3 minimum full-load efficiency values are virtually to the North American National Electrical Manufacturers Association (NEMA) Energy Efficient and Premium Efficiency motor standards, respectively. NEMA specify different full-load efficiency values for motors Totally Enclosed Fan-Cooled and Open Drip-proof enclosures and from 200HP IEC IE3 efficiency is slightly higher than

TABLE I
COMPARABLE EFFICIENCY LEVELS AND CLASSES

	Efficiency Levels	Comparison
IE1	Standard Efficiency	
IE2	High Efficiency	For 50 Hz considerably higher than EFF2 of CEMEP and identical to the U.S. EPAct for 60 Hz
IE3	Premium Efficiency	New efficiency class in Europe for 50 Hz, higher than EFF1 on CEMEP and with some exceptions identical to NEMA Premium in the United States for 60 Hz.

NEMA Premium Efficiency. The IEC minimum full-load efficiency standards are higher for 60 Hz motors than for 50 Hz motors. This is because as long as the motor torque is constant, I^2R or winding resistance losses are the same at 50 Hz and 60 Hz. The motor output power, however, increases linearly with speed, increasing by 20% when the frequency is increased from 50 Hz to 60 Hz. Generally, the 60 Hz efficiency is about 2.5% to 0.5% greater than the 50 Hz values [6]. The efficiency gain is greater for smaller motor power ratings. To ensure compliance with these new efficiency standards,motors must be tested in accordance with the newly adopted IEC60034-2-1 testing protocol. This procedure provides test results that are largely compatible with those obtained by North American IEEE 112B and CSA 390 test methods [6]. The new standard also requires that the motor efficiency class and normal motor efficiency be labeled on the motor nameplate and given in product literature and motor catalogues. By July 22, 2009, Commision Regulation (EC) No 64/2009 implementing Directive 2005/32/EC states that in the EU, with the exception of some special applications, motors shall not be less efficient than the IE3 efficiency level as from January 2015 [6].

. IE2 by june 16, 2011.
. IE3 by January 1, 2015 (for motors greater or equal to 7.5 to 375 kW) and IE2 only in combination with an *adjustable speed drive*
. IE3 for all motors by January 1, 2017, (for motors from 0.75 to 375) and IE2 only in combination with an *adjustable speed drive*.

The low voltage motor have been seen to be mostly unefficient, due the IEC 60034-30-1 standard on efficiency classes for low voltage AC motors. The standard on efficiency classes of line operated AC motors was published by the international Electrotechnical Commission (IEC) on March6,2014. This IEC standard is concerned with global hamonization of energy efficiency classes for electric motors. Compared with IEC/EN 60034-30:2008, it significantly expands the range of products covered with the inclusion of 8-pole motors and introduction of IE4 efficiency performnce class for electric motors. All technical constructions of motors are covered as long as they are rated for direct on-line operation. Whereas the previous edition covered only three-phase products, the new standard also includes single-phase motors, as well as line-start permanent magnet motors.

4) Efficiency classes defined by IEC/EN 60034-30-1: 2014: This standard defines four IE (International Efficiency) efficiency classes for single speed electric motors that are rated according to IEC 60034-1 or IEC 60079-0 (Explosive atmospheres) and designed for operation on sinusoidal voltage [7].

. IE4: Super-Premium efficiency
. IE3: Premium efficiency.
. IE2: High efficiency.
. IE1: Standard efficiency.

IE efficiency classes for 4 pole motors at 50 Hz. The power

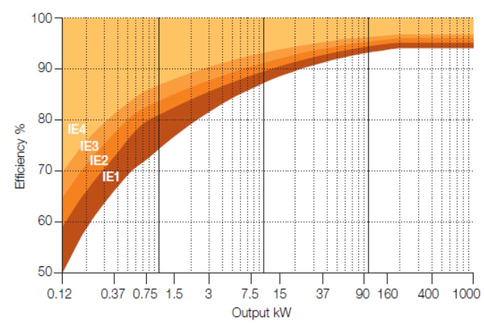

Fig. 15. IE efficiency classes for 4 pole Motors at 50 Hz [7]

IEC/EN 60034-30-1	EU MEPS	EISA US EEV Canada	Other, similar local regulations
IE4 Super-Premium efficiency			
IE3 Premium efficiency	IE3 Premium efficiency	Identical to NEMA Premium efficiency	Japan 2015 Australia/New Zealand 2015 Korea 2015 China 2016
IE2 High efficiency	IE2 High efficiency	Identical to NEMA Energy efficiency/ EPACT	Canada Mexico Australia New Zealand Brazil
IE1 Standard efficiency		Below standard efficiency	Costa Rica Israel Taiwan

Fig. 16. Standard Comparison [7]

range covered by this standard has been expanded to cover motor from 120 W to 1000 kW.

VI. ELECTRIC DRIVES IN CRANES

A *Crane* is a type of machine, mostly equipped with a *hoist, wire ropes* or *chains*, and *sheaves*, that can be used both to lift and lower materials and to move them horizontally. It is mainly used for lifting heavy things and transporting them to other places. It uses one or more *simple machines* to create *mechanical advantage* and thus move loads beyond the normal capability of a human. Cranes are commonly employed in the *transport* industry for the loading and unloading of freight, in the *construction* industry for the movement of materials and in the manufacturing industry for the assembling of *heavy equipment*. The first construction cranes were powered by men or beasts of burden, such as donkey. Larger cranes were later developed, employing the use of human *treadwheels*,permitting the lifting of heavier weights [8].The modern cranes usually use the *Internal combustion engines* or *electric motors* and *hydraulic* systems to provide a much greater lifting capability than was previously possible. This section will be focusing on the cranes that are powered by *electric motors*

A. Electrical technology for cranes

Electrical technology for cranes control has undergone a significant change with the time. From Ward Leaonard system to DC drive and the advent of power IGBTs during 1990s enabled the introduction of the AC drive [8]. The conventional AC operated crane drives use slip ring induction motor whose rotor windings are connected to power resistance in 4 to 5 steps by power contactors. Reversing was done by changing the phase sequence of the stator supply through line contactors. Braking is achieved by plugging. The main disadvantage is that the actual speed depends on the load.An electronic control system has recently been added to continuously control rotor resistor value. Currently, all of these systems are replaced by frequency converter supplied squirrel-cage induction motors for all types of motion. Control concept based on application of programmable logic Controllers (PLC) and industrial communication networks.

B. Power Converters in cranes

An overhead and gantry cranes are typically used for moving containers, loading trucks or storage materials. These cranes usually consist of three separate motions for transporting material. The first motion is the hoist, which raises and lowers the material. The second is the trolley, which allows the hoist to be positioned directly above the material for placement. The third is the gantry or bridge, which allows the entire crane to be moved along the work area. Very often, in industrial applications additional drives as auxiliary hoist, power cable and conveyer belt are needed. Therefore, generally, a crane is complex machinery. Depending on the crane capacity, each of the mentioned drives, can be realized as multi-motor. The term multi-motor drive is used to describe all drives in the technological process. If the controlled operation of the drives is required by the process based on the controlled speed of the individual drives, the expression controlled multi-motor drives is adequate. For many such drives, the machanical coupling on the load side is typical. The controlled drives are usually fed from the power converter, which is also true for controlled multi-motor drives. The kind, the type and the number of converters used depend on the type of motors, their power ratings, and of the kind of multi-motor drive. The control and regulation also depend on the type of the multi-motor drive, but also the type of the converter selected, therefore the selection of the converter and the controller for these drives must be analyzed together. Considering the power supply of the motor, the following cases are possible

- Multi motors fed by a single converter (multi motor-single converter).
- Motors controlled by separate converters (multi motors-multi converters).

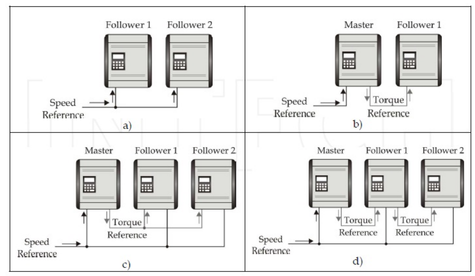

Fig. 17. Different type of converter configurations [8]

In crane applications multi-motor drives are used very often and a proportional share of power between motors is required. Load sharing is a term used to describe a system multiple converters and motors are coupled and are used to run the mechanical load. In another way, load sharing means that the amount of torque applied to the load from each motor is prescribed and carried out by each converter and motor set. Therefore, multiple motors and converters powering the same process must contribute its proportional share of power to the driven load. Multiple motors that are run from a single converter do not load share because torque control of individual motors is not possible. The load distribution, in that case, is influenced only by the correct selection of the torque speed mechanical characteristics. For the squirrel cage induction motors, there is no economical method for the adjustment of the mechanical characteristic of the ready made motors, but this has to be done during the selection. For the slip-ring induction motor, the mechanical characteristic can be adjusted afterwards, with the inclusion of the rotor resistors. Motors that are controlled by separate converters without any interconnection also do not share the load. The lack of interconnection defeats any possible comparison and error signal generation that is required to compensate for the difference in the laod that is applied to any single drive and motor set.

C. Use of ASD

The cranes work with variable loads, so in order for the machine (mostly induction motor) to handle this type of operation process the adjustable speed drive (ASD) has to be used. ASD in low and mid power range are normally based on the concept of variable voltage, variable frequency (VVVF) as it is shown in fig.(18). Generally the classification divides

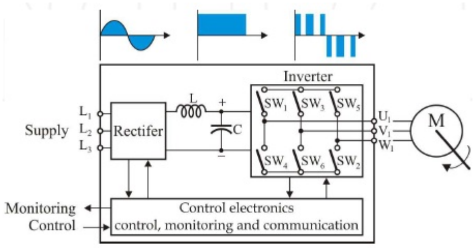

Fig. 18. Variable Speed Drive [8]

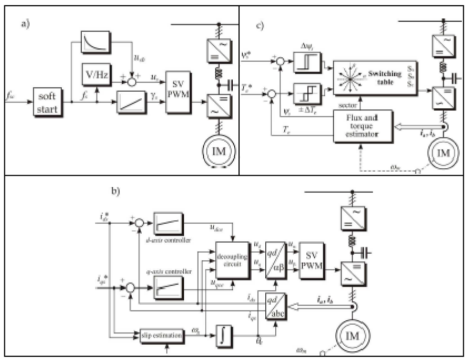

Fig. 19. Control Scheme [8]

the induction motor control schemes into scalar and vector based methods. Opposite to scalar control, which allows control of only output voltage magnitude and frequency. Those different ways are illustrated in fig.(19), where a) illustrates a V/Hz open loop control scheme; b) illustrates two inner PI-controlled current loops for d and q stator current components and c) shows the basic version, direct torque control(DTC) consists of a three-level hysteresis comparator for torque control and two-level hysteresis comparator for flux control.

D. Regeneraive Braking

In order to have a dynamic braking in cranes, most of power electronics options can be used, but the most used are:*Voltage source inverter with diode front end rectifier and dynamic brake module* and *Active front end inverter*. the overview on these two cases can be seen in lines below.

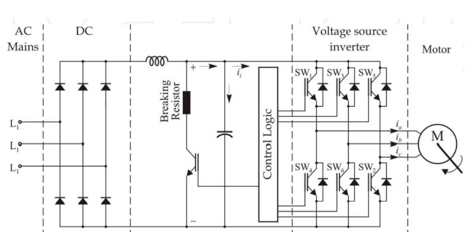

Fig. 20. Voltage source inverter with diode front end rectifier and dynamic brake module [8]

1) Voltage source inverter with diode front end rectifier and dynamic brake module: From fig.(20) a dynamic brake consists of chopper and a dynamic brake resistor.It illustrated a simplified dynamic braking schematic. The chopper is the dynamic braking circuitry that senses rising DC bus voltage and shunts the excess energy to the dynamic brake resistor. A chopper contains three significant power components: The chopper transistor is an IGBT.The chopper transistor is either ON or OFF, connecting the dynamic braking resistor to the DC bus and dissipating power, or isolating the resistor from the DC bus. The current rating of the chopper transistor determines the minimum resistance value used for the dynamic braking resistor. The chopper transistor voltage control regulates the voltage of the DC bus during regeneration. The dynamic braking resistor dissipates the regenerated energy in form of heat.

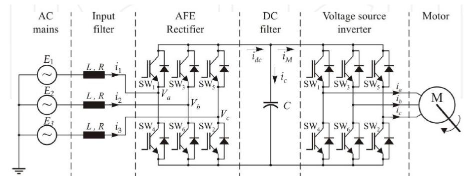

Fig. 21. Active front end inverter [8]

2) Active front end inverter: From fig.(21), it is illustrated, one of the alternative circuitry that can be used to recover the load energy and return it to the power supply. And it seems to be the most popular topology used in ASD. The diode rectifier is replaced with a PWM voltage source rectifier. It is already an implemented technology and known as most successful active front end solution in ASD. Once used in cranes, the cranes system can take power when the system is motoring but also, giving power back to the grid when the system is braking. With this technology, the crane system produce a very big amount of regenerative braking energy and supply back to the grid, or used in other needs.

3) Related Technologies: Apart from cranes, the same technology can be applied in big and tall buildings. Where elevators and escalators are used. The machines used to animate these systems will need ASD; as these are the systems with variable loads. Depending on the will of the building owner, the energy produced during regenerative braking can be used in other different needs or supplied back to grid.

VII. CONCLUSION

In conclusion, as the title of this work shows it; the purpose was to asses the impact of the electric drives in efficient use of electric machines. The development of electric drives drastically developed the use of electric machines. As it was supposed at the early use of induction machines; it was not easy to use them at variable speed or to animate variable loads. Actually with electric Drives induction motor can be used in various applications, and its use can be controlled, due it is efficient. The electric drives development have caused the development of the new version of electric machines which are more efficient as small in size; including *Permanent magnet synchronous machines* and *Synchronous reluctance machines*.The electric drives have had a strong impact on the electric motor efficiency classifications and standardizations; actually standards require the use of electric drives. The last ones also have opened a way for good use of energy in machinery system. Due to electric drives control, the system can consume or produce energy that can be used in other purposes, or sent back to grid. Electric drives have opened a wide way to different researches on machines.

REFERENCES

[1] Electrical machines - electric drives (fundamentals). [Online]. Available: http://www.mpoweruk.com/machines.htm

[2] J.M.C.Rodriguez, “The induction machine.”

[3] Starting and control of three-phase asynchronous motors. [Online]. Available: www.eaton.com

[4] T. L. Skvarenina, *THE POWER ELECTRONICS HANDBOOK,Industrial Electronics Series*.

[5] J. Puig, “International lv motor efficiency standard.”

[6] Premium efficiency. [Online]. Available: http://en.wikipedia.org/wiki//Premium$_efficiencycite_note-autogenerated1-7$

[7] “Technical note iec60034-30-1 standard on efficiency classes for low voltage ac motors.”

[8] V. K. Nebojsa Mitrovic, Milutin Petronijevic and B. Jeftenic , “Electric drives for crane application.”