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COMPARISON BETWEEN AC DRIVE AND DC DRIVE FOR CRANES AT PORT SAID CONTAINER TERMINAL

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ABSTRACT

This paper presents a comparison between the control system performances of different cranes work at Port Said Container Terminal. These cranes work with different control systems such as DC drive, AC drive and Active Front End drive. Comparison has been done between two drive systems, DC drive and Active Front End drive (AFE). The advantages and disadvantages are discussed and summarized.

1. INTRODUCTION

Active Front End is used to achieve the controllable DC voltage at the output with the sinusoidal input current at unity power factor. In the real system supply voltage always contains lower harmonics, most commonly the 5^{th} and the 7^{th} harmonic [1].

It has been noticed later from watching power factor meter that the (power factor) has improved. This is due to entering Active Front End drive system of Cranes 106,109 in the network .They work by AC Induction motors**.**

Active front end drive system and the simulation results by matlab software is explained.

The papers include:

Explanation of the different electrical operating systems on the cranes and figures of electrical wave on all the cranes by using oscilloscope:

- **Ward Leonard speed control that is used in cranes 101,102:**
  The first operating system is Ward Leonard speed control that is used in 101,102 cranes, they use DC MOTOR.
- **Speed control by Thyristor Drive that used in cranes 105,107 and 108:**
  The second operating system is speed control that uses DC drive using Thyristor on 105,107 and 108 cranes, they use DC MOTOR.
- **Speed Control by Thyristor and Diode Drive that used in cranes 103 and 104:**
  The third operating system is speed control that uses DC drive using Thyristor and Diode on 103 and 104 cranes, they use DC MOTOR.
- **Active Front End System on cranes 106 and 109:**
  The last operating system is Active Front End drive system of induction motor. These methods convert from AC to DC and vise versa.
- **Matlab Simulation of Active Front end:**
  This part includes Simulation of Active Front End by using matlab software and Comparison between the simulations of the AFE wave shapes results using matlab Simulink and the measurement results.
- **The values of active and reactive power during different movements of cranes 106, 109:**
  This part includes the values of generated and consumed power during cranes different movements.
- **Results dissuasion in side medium voltage (11KV) for active and reactive power:**
  Power meter of the medium voltage (11KV) for active and reactive power have been recorded during different movement of cranes**.**

2. SPEED CONTROL METHODS

2.1. Ward Leonard speed control that is used in cranes 101,102

This method was followed by the rotating M-G system of Ward Leonard patented in the 1890's. This drive used an AC motor driving a DC generator to convert AC to DC power.

The motor and generator may be combined in a single frame and use a common shaft, or separate coupled units as shown in figure 1.

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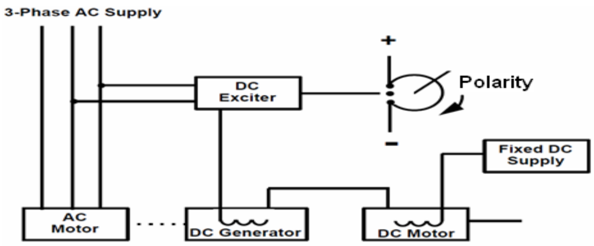


Fig.1: block diagram of Ward Leonard system

The output DC voltage is controlled by adjusting the field excitation of the DC generator. Depending on the accuracy required, armature voltage or a tachometer may be used as a feedback signal in a closed loop system. An important aspect of this drive is that power flow is reversible. The motor acts as a generator,

driving the generator as a motor, which drives the AC motor which then pumps power back into the AC lines. This ability, called regeneration, is a useful feature in decelerating large inertias or holding back overhauling loads [2].

This system generates pure DC voltage from DC generator because it doesn't use power electronic drives if we see the voltage wave form on oscilloscope we find pure DC voltage as shown fig.2:

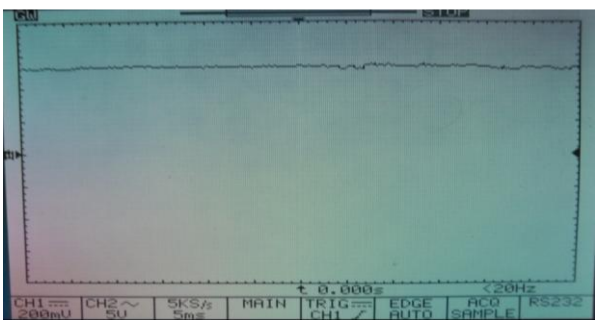


Fig.2: measured DC voltage of DC generator

In this system power factor correction unit is needed to compensate reactive power drawn by AC motor. The value of harmonic order is very small as the system doesn't use power electronic devices. The input voltage wave forms of the crane when it hoists up and down as shown fig.3 and 4:

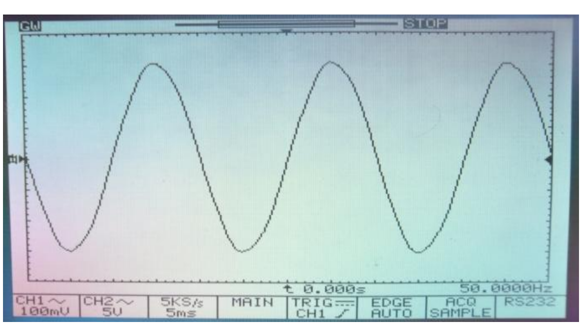


Fig.3: AC input voltage wave form during hoist up

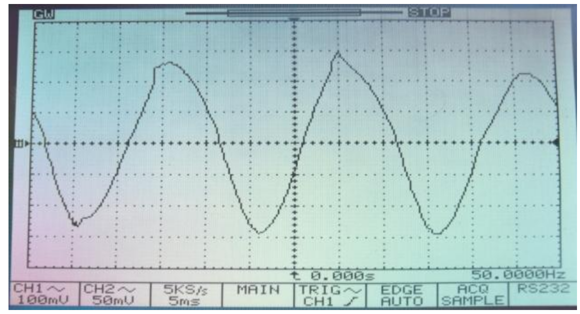


Fig.4: AC input voltage wave form during hoist down

Notice the wave distortion in the case of hoisting down rather than hoisting up. That is due to power generated by the motor in regenerative mode.

2.2. Speed control by Thyristor Drive that used in cranes 105,107 and 108:

This system uses power semiconductor device to convert the AC supply to DC and control **DC MOTOR** speed by using thyristor drive. This system was fabricated by **LIEBHERR COMPANY**. Liebherr fabricated system uses the values of load, torque, speed and set point, these values are taken from regulation control electronic boards as shown in table (1) and control cared diagram as shown in fig.5:

Table (1): Different regulation boards:

load meter card	load cell card
over load comparator card	over load summing card
electronic supply card	motor field card
set value card	stopping logic card
hyperbolic calculator card	integrator card
speed control card	Torque logic card
pulse generator card	pulse amplifier card
motor field regulator card	Motor field card
Supply over load card	Total load meter card
Speed regulator card	Current regulator card
Current feed back card	Pulse generator card
Pulse amplifier card	Tacho monitor card

The drive has internal computer system that use the values from the regulation boards to estimate the output value represented in the form of thyristor switching pattern that comes from the triggering module as shown in fig.5 .[3]

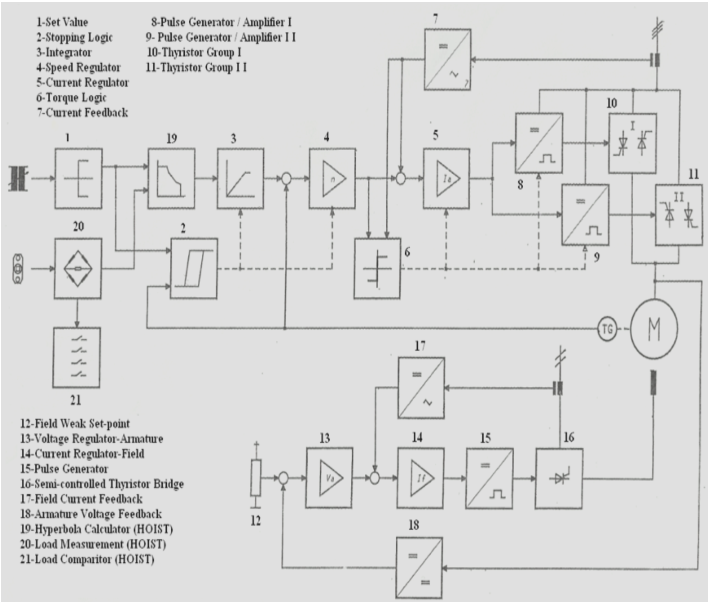


Fig 5: Block diagram of control cared

The drive converts AC supply to DC by using thyristor drive system as shown fig.6: [3]

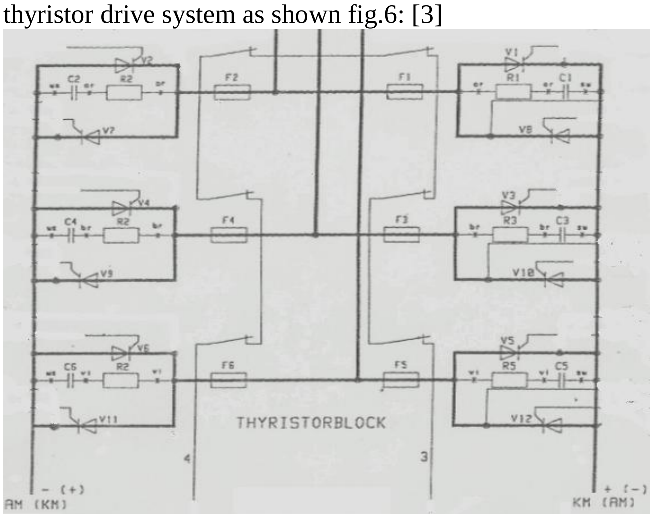


Fig 6: Block diagram of thyristor drive system

In these cranes power factor correction unit is needed because using power electronic devices distorts the sin wave due to generated harmonic. The AC input sin wave when the crane makes different motions is distorted as shown fig.7. In this system the drive generated DC voltage is shown in fig. 8.

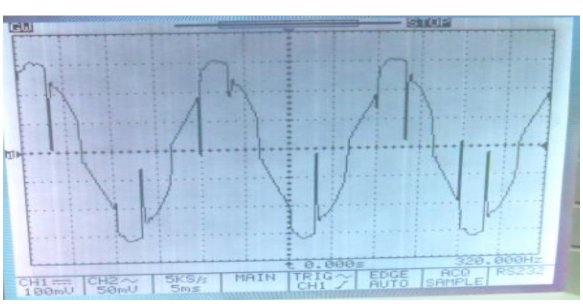


Fig 7: AC voltage measured on operation mode

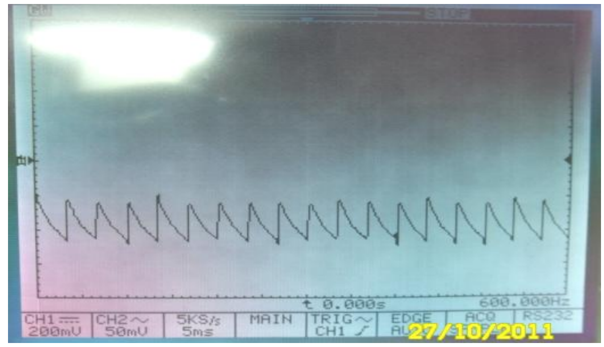


Fig 8: DC voltage generated measured of drive

2.3. Speed Control by Thyristor and Diode Drive that uses in crane 103 and 104

In this method use power semiconductor device, to convert the AC voltage supply to DC voltage. Control the speed of DC MOTOR by using DC drive, this drive using thyristor and diode to generate variable voltage and currant in armature and filed in DC motor. This system was fabricated by Siemens .The drive controls DC motor by using program, this program calculates the torque, the load of container by load cell, and the feed back speed value from encoder. By this closed loop system the speed of containers can be controlled while carrying different loads. The drive uses four Quadrant systems as shown in fig.9: [4]

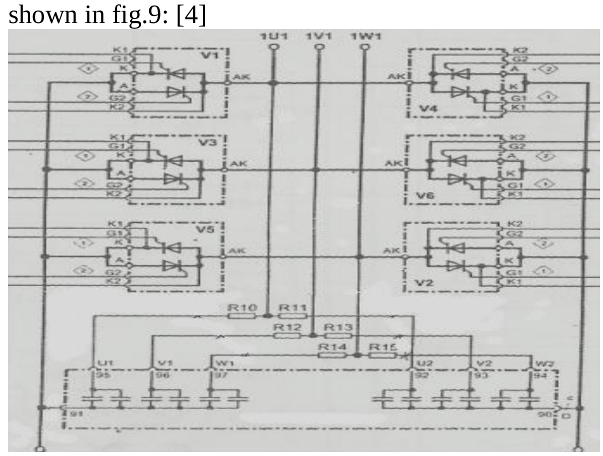


Fig 9: Drive circuit diagram

The 12 back to back thyristors generate DC armature current, in field bridge rectifier four thyristors and two diodes are used to control field voltage, capacitor bank is used to smooth output DC wave form applied to motor as shown fig.10:

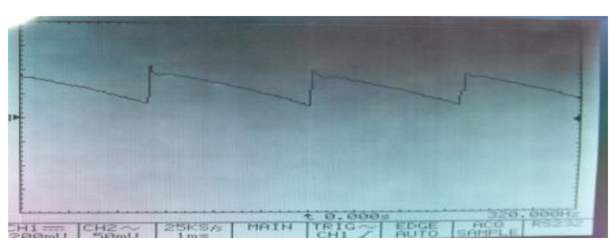


Fig 10: DC wave measured out put from drive

In this system also power factor correction unit is needed like the previous system because the power electronic device distorts the sin wave input as shown fig. 11, 12 and 13.

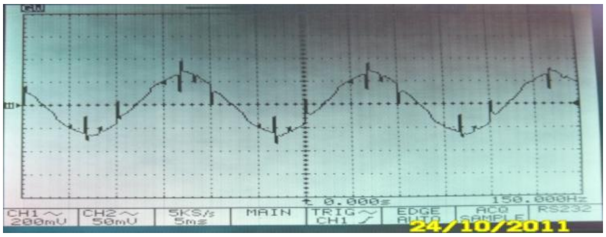


Fig 11: AC voltage measured on OFF mode

Fig 12: AC voltage measured during hoist down motion

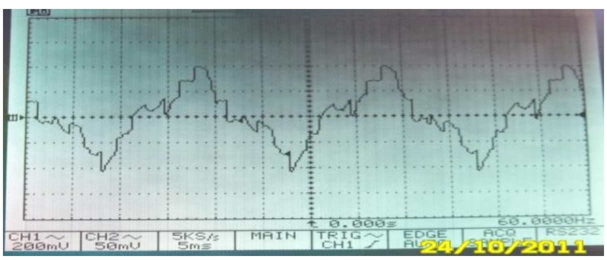


Fig 13: AC voltage measured during hoist up motion

2.4. Active Front End System on cranes 106 and 109.

AFE Description

The AFE (Active Front End) rectifier/regenerative feedback units belonging to the SIMOVERT MASTERDRIVES series are power electronics devices that are available as cabinet and chassis units.

The units can be operated on a 3 phase mains with or without an earthed neutral point.

The core component of the AFE rectifier/regenerative feedback unit consists of a voltage source converter with the control unit and it generates a controlled DC voltage, the so-called DC link voltage, from a 3-phase mains.

This DC link voltage is kept constant almost independently of the mains voltage (also in the event of regenerative feedback). The prerequisite for this is that the DC voltage set point is within the operating range defined below.

DC link voltage operating range

Minimum:

1.5 times the rms value of the applied mains voltage.

Explanation: the DC link voltage of the AFE inverter must at least be greater than the peak rectified value of the applied mains voltage to ensure that the power system is no longer controlled via the freewheeling diodes of the IGBT switches.

Maximum:

For the 400 V mains voltage range: 740 V DC

500 V mains voltage range: 920 V DC

690 V mains voltage range: 1100 V DC

Operating principle

On the 3-phase end, a mains angle-oriented high-speed vector control is subordinate to the DC link voltage control and impresses an almost sinusoidal current on the network so as to minimize system perturbations with the aid of the subsequently connected Clean Power filter [5].

The vector control also enables setting of the power factor cosφ, and thus reactive power compensation, but the operating current requirement has priority.

The VSB module (Voltage Sensing Board), functions as the network angle sensor, similarly to the principle of an encoder.

For safety reasons, an AFE rectifier/regenerative feedback unit must be connected to the mains via a main contactor; as shown fig.14:

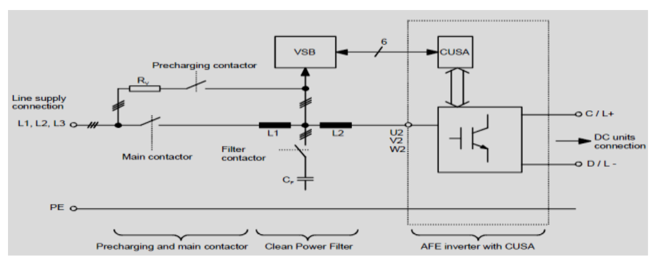


Fig. 14: AFE Basic block diagram

Both one and several inverters can be connected to the output.

The maximum connected power of the inverters may amount to 4 times the rated power of the AFE inverter. The sum of active power extracted from the network must not exceed the rated power of the AFE, and this must be ensured by configuration of the system.

The AFE is suitable for coupling several inverters to a common DC busbar. This allows energy to be transferred between motoring and generating drives, thus providing a power-saving feature.

Line voltage dips can be bridged in voltage step-up operation without altering the DC link voltage value. This can be achieved up to 65 % of rated line voltage without additional components on condition that the power balance defined by Equation 1 can be maintained.

$$\sqrt{3} \cdot V_{line} \cdot I_{max} = V_d \cdot I_d \quad \text{-------------} \ (1)$$

To bridge line voltage dips below 65 % of rated line voltage, the auxiliary power supply must be supported by an external UPS or similar to prevent the contactors from dropping out [5].

The Active Front End Inverter refers to the power converter system consisting of the line-side converter with active switches such as IGBTs, the DC-link capacitor bank, and the load-side inverter. The line-side converter normally functions as a rectifier. But, during regeneration it can also be operated as an inverter, feeding power back to the line. The line-side converter is popularly referred to as a PWM rectifier in the literature. This is due to the fact that, with active switches, the rectifier can be switched using a suitable pulse width modulation technique.

The PWM rectifier basically operates as a boost chopper with AC voltage at the input, but DC voltage at the output. The intermediate DC-link voltage should be higher than the peak of the supply voltage [6]. This is required to avoid saturation of the PWM controller due to insufficient DC link voltage, resulting in line side harmonics. The required DC-link voltage needs be maintained constant during rectifier as well as inverter operation of the line side converter. The ripple in DC-link voltage can be reduced using an appropriately sized capacitor bank. The active front-end inverter topology for a motor drive application is shown in Figure 15:

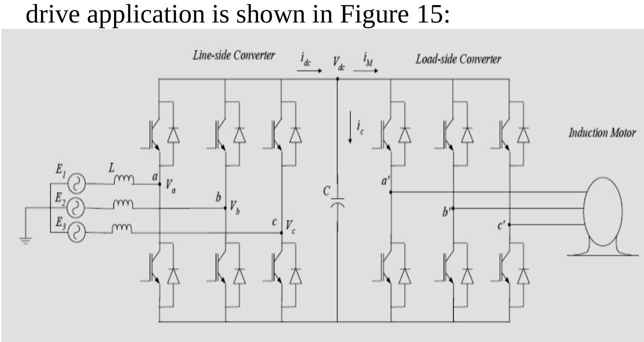


Fig. 15: Block diagram of Active front end induction motor drive system

The topology shown in Figure 18 has two three-phase, two-level PWM converters, one on the line side, and another on the load side. The configuration uses 12 controllable switches. The line-side converter is connected to the utility through inductor [6].
The inductor is needed for boost operation of the line-side converter. A transformer on the supply side with appropriate secondary impedance also serves the same purpose.

For a constant DC-link voltage, the IGBTs in the line-side converter are switched to produce three-phase PWM voltages at a, b, and c input terminals. The line-side PWM voltages, generated in this way, control the line currents to the desired value. When DC-link voltage drops below the reference value, the feed-back diodes carry the capacitor charging currents, and bring the DC-link voltage back to reference value.

A per-phase equivalent circuit of the three-phase, line-side PWM converter is shown in Figure 16. The source voltage *ES*, and line inductance *L* represent the utility system. The three-phase voltages at the three input legs of the line side converter are represented by *V*. The voltage *V* can be viewed as a PWM voltage wave constructed from the DC link voltage *Vd*. The magnitude and phase of the fundamental component of *V* is controlled by the line-side converter. The voltage *VL*, across inductor ***L***, is ***ISωL*** where, ***ω*** is the angular frequency of supply voltage. Note that, the synchronous machine connected to an infinite bus can also be represented by the same per-phase equivalent circuit shown in Figure 16. Similar to an overexcited or under-excited synchronous machine, the PWM converter can also draw line currents at leading, lagging or unity power factor.

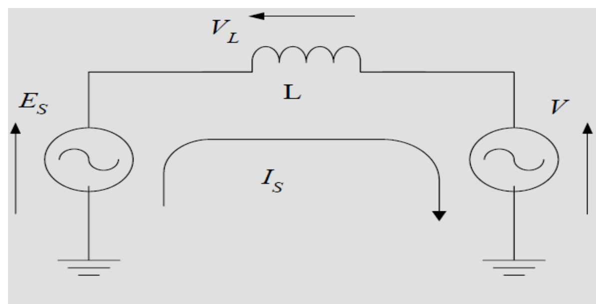


Fig.16: Per-phase equivalent circuit

As illustrated in Figure 17(a), for unity power factor operation in rectifier mode of the line-side converter, the PWM voltage ***V*** needs to be larger than the supply voltage phasor ***ES*** in magnitude and lags ***ES*** by an angle ***δ***. This makes *ES* and line current ***IS***, to be co-phasal. The angle ***δ*** is called the power angle because it controls the power flow between the two sources.

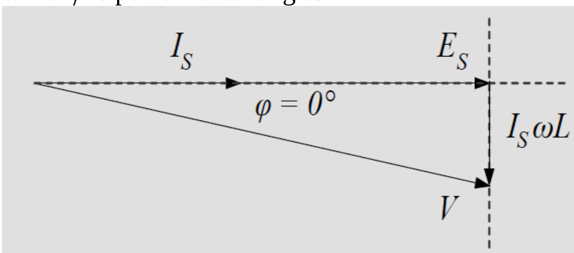
The regenerative mode of the line-side converter is shown in Figure 17(b). The ***IS*** *phasor* now reverses, causing reversal of ***ISωL*** phasor. In order to satisfy the phasor diagram, the ***V*** phasor should lead phasor *ES* by an angle *δ*. Thus the power angle ***δ*** also reverses. Likewise, the leading power factor operation is illustrated in Figure 17(c).

The active power ***P***, and reactive power ***Q***, are given by following expressions:

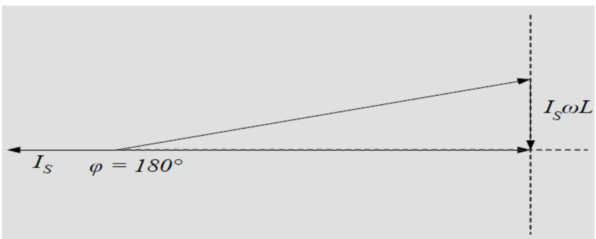
$$P = 3 \cdot E_S I_S \cos\varphi \qquad \text{--------------------} \ (2)$$

$$Q = 3 \cdot E_S I_S \sin\varphi \qquad \text{--------------------} \ (3)$$

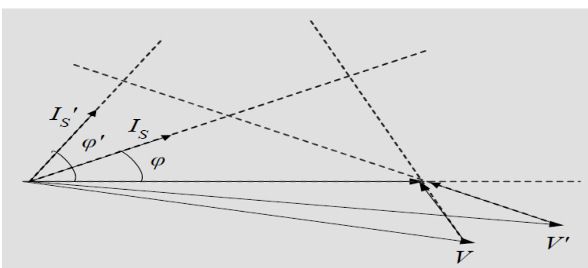
Where *ES* and *IS* are supply voltage and line current, while φ is power factor angle.



a)Unity power factor during motoring mode



b) Unity power factor during regenerating mode



c) Leading power factor operation during motoring mode

Fig. 17: operating principle

From Figure 17 (b) equations can be written as follow,

$$I_S \omega L \cos\varphi = V \sin\delta \quad \text{---------------- (4)}$$

$$I_S \omega L \sin\varphi = V \cos\delta \quad \text{---------------- (5)}$$

Substituting the values of *IS*cosφ and *IS*sinφ in Equation (2) and (3) respectively,

$$P = 3 \cdot E_S \frac{V \sin\delta}{\omega L} \quad \text{---------------- (6)}$$

$$Q = 3 \cdot E_S \frac{V \cos\delta - E_S}{\omega L} \quad \text{---------------- (7)}$$

The equations (2) through (7) indicate that the PWM voltage, ***V***, and power angle, ***δ***, can be controlled to control active and reactive power. It is also possible to maintain reactive power constant while varying active power. This is done by keeping phasor **Vcosδ** constant and varying phasor **Vsinδ** [7].

3. Matlab Simulation of Active Front end

For the purpose of fast response, the control is carried out in the ***d-q*** reference frame. This type of control is referred to as ***'field-oriented'*** control. The starting point of the control is the system of non-linear differential equations which characterizes its behaviour. As derived previously, the dynamics of an active front-end converter are given by a system of differential equations stated below,

$$L\frac{di_{qe}}{dt} = E_{qe} - \omega L i_{de} - R i_{qe} - V_{qe} \quad \text{-------------------- (8)}$$

$$L\frac{di_{de}}{dt} = E_{de} + \omega L i_{qe} - R i_{de} - V_{de} \quad \text{------------------ (9)}$$

The differential equation governing dc-link voltage also needs to be added to the above set of system equations to completely define system dynamics [8].

$$C\frac{dV_{dc}}{dt} = i_{dc} - i_M \quad \text{---------------------- (10)}$$

where, *idc* is the total dc-link current supplied by the rectifier, while *iM* is the load-side dc current which is the result of induction motor operation. The *idc* and *iM* currents are shown in Figure 18. Figure 19 and 20 show ac and dc side equivalent circuits respectively.

The dc current, *iM*, can be viewed as a noise in dc-link voltage *Vdc* [9].
A positive *iM* (motoring-mode) will discharge the dc-link, while a negative *iM* (regeneration-mode) will charge the dc-link to a higher potential. If the dc-link current *idc* supplied by the line-side converter equals to *iM*, then we have,

$$C\frac{dV_{dc}}{dt} = 0 \,. \quad \text{------------------------ (11)}$$

In other words, dc-link voltage remains constant.

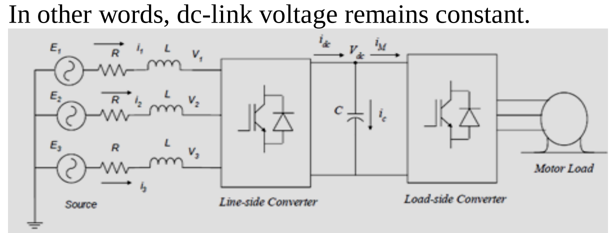


Fig.18: DC-link dynamics controlled by line-side converter

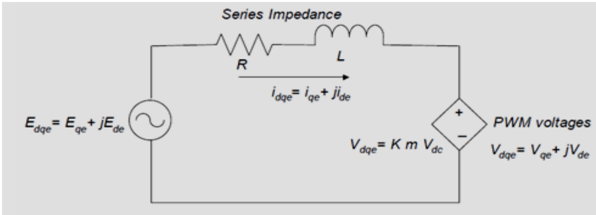


Fig.19: AC-side per-phase equivalent circuit

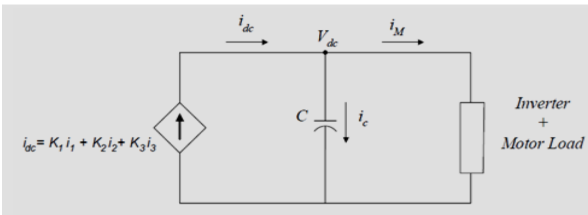


Fig.20: DC-side equivalent circuit of an active drive

In Equation (8) , the terms *Eqe* and *Ede* are computed from source voltages, *E1*, *E2*, and *E3*. Since line voltages are known, the angular frequency, ω, can be easily estimated [10].

The PWM voltages *Vqe* and *Vde* are the two inputs to the system which are generated using the sine-triangle PWM controller. *LS* and *R* represent series impedance.

Figure 19 illustrates ac-side per-phase equivalent circuit representation of Equation (8) . *Vdqe* appears as a controlled voltage-source which is a function of a modulation index and dc-link voltage *Vdc*. On the other hand, Figure 20 shows dc-side equivalent circuit representation of Equation (9) . The dc-link current, *idc*, appears as a current source, which controls the capacitor voltage while supplying the current required by the motor load.

4. The simulation model of Active Front End by using Simulink:

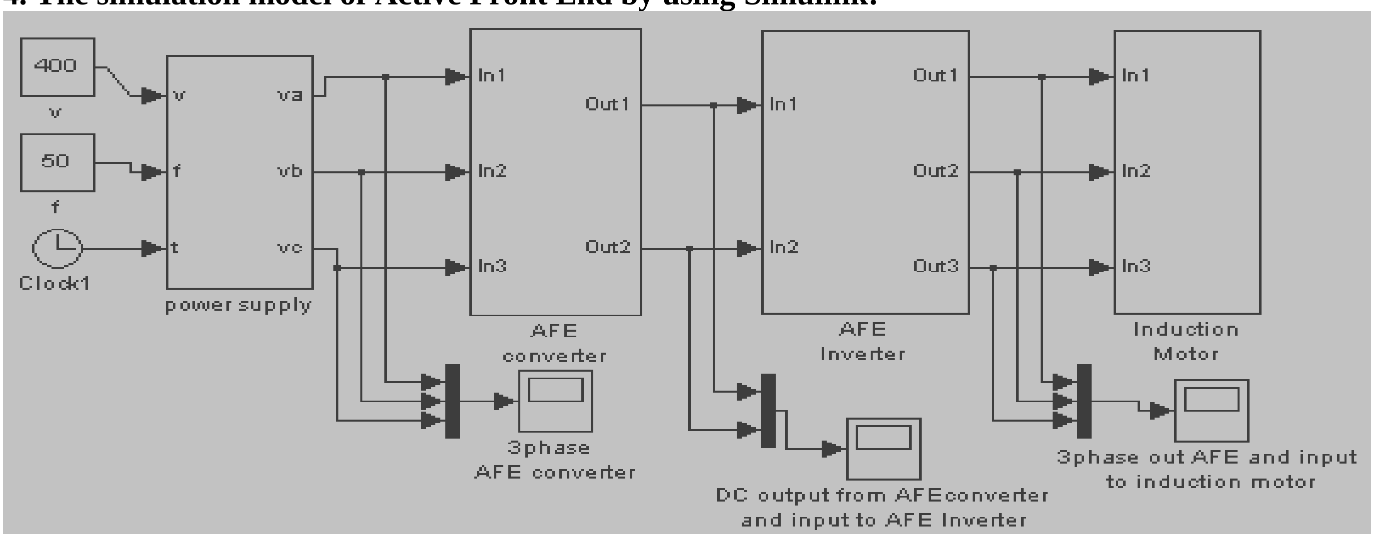


Fig.21: Block diagram of Active Front End induction motor drive system in matlab Simulink program

4.1. The AC power Supply:

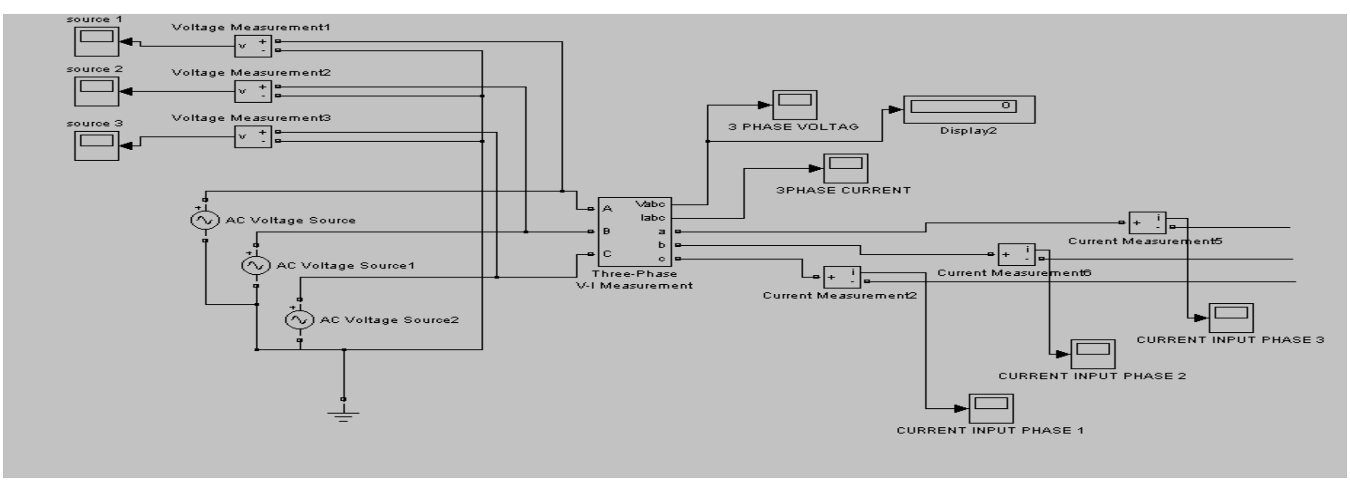


Fig.22: AC Supply

4.2. The Active Front End Converter(AC to DC):

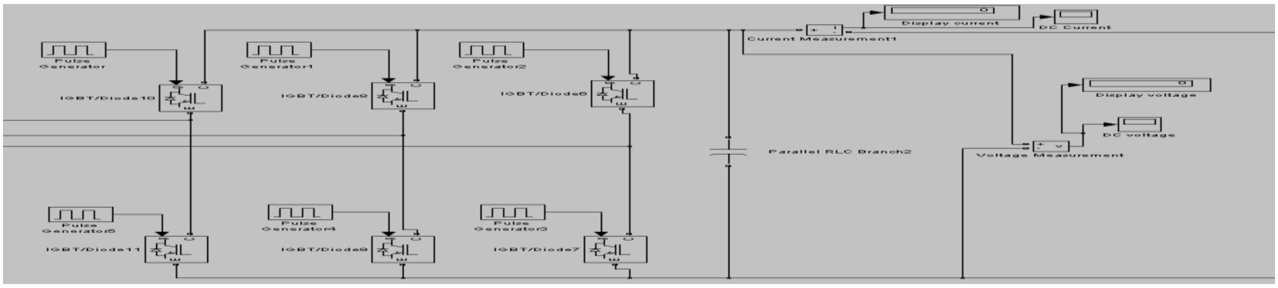


Fig.23: AFE Convert AC to DC

4.3. The Active Front End Inverter(DC to AC):

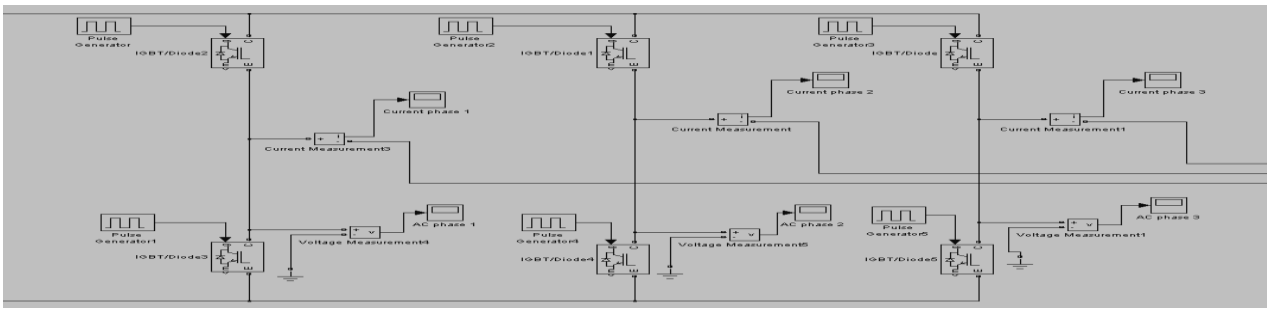


Fig.24: AFE Inverter DC to AC

4.4.The Induction Motor:

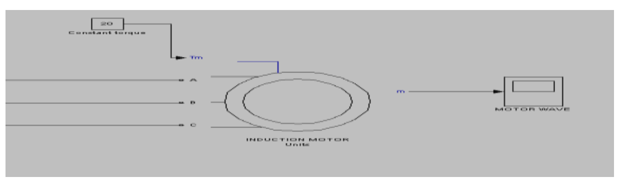


Fig.25: Induction Motor

5. Experiential results compared with Simulink results:

A- The AFE input sin wave while hoisting up with container 20 ton:

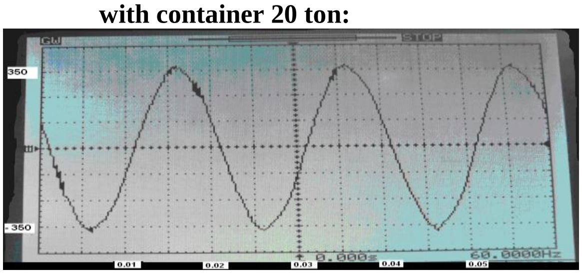


Fig.26: Results taken by oscilloscope

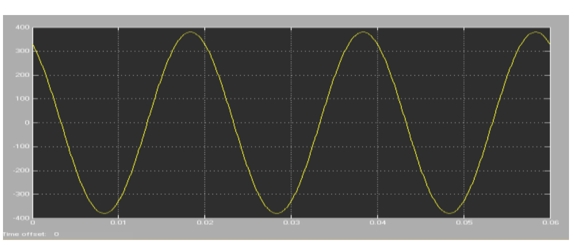


Fig.27: Results taken by Simulink software program

These results are taken while lifting a container 20 ton . it is noticed that the results from oscilloscope and the Simulink is the same . the voltage beak is almost 350 volt and the periodic time is 0.02 sec .

B- The output DC from AFE:

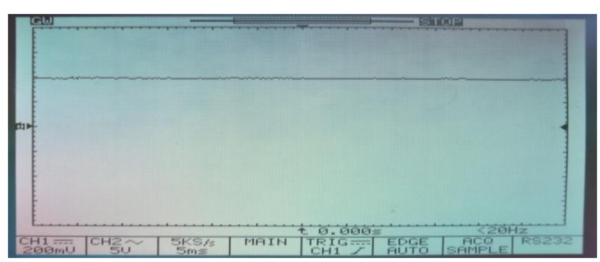


Fig.28: Results taken by oscilloscope

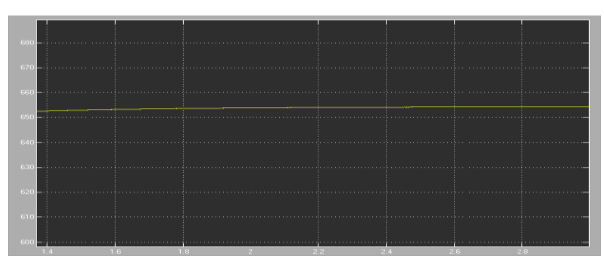


Fig.29: Results taken by Simulink software program

It is noticed that the voltage at dc link is almost pure dc .This is a big advantage of the using active front end systems , low ripples dc wave , high power factor and also low level of harmonic distortion .the dc voltage shown is 655 V.

C- **The output sin wave from AFE inverter while hoisting up with container 20 ton:**

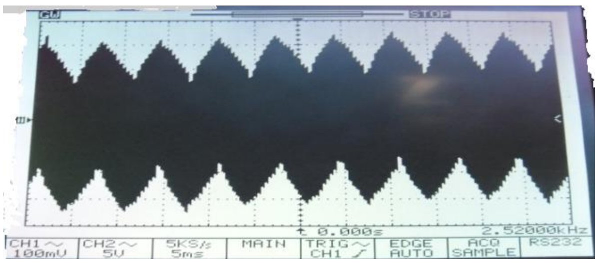


Fig.30: Results taken by oscilloscope

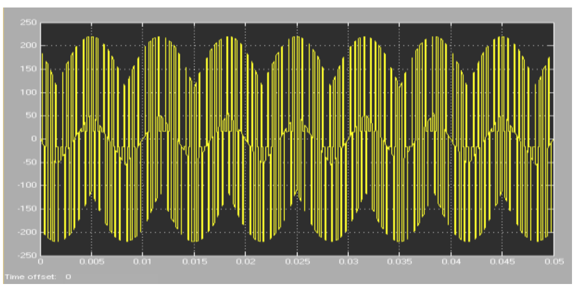


Fig.31: Results taken by Simulink software program

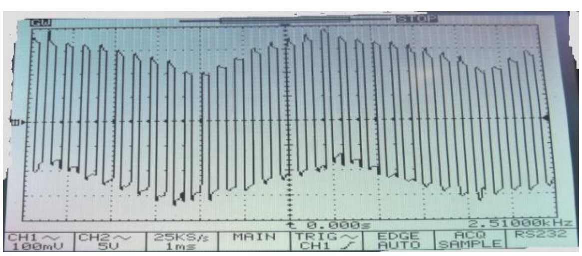


Fig.32: Results taken by oscilloscope

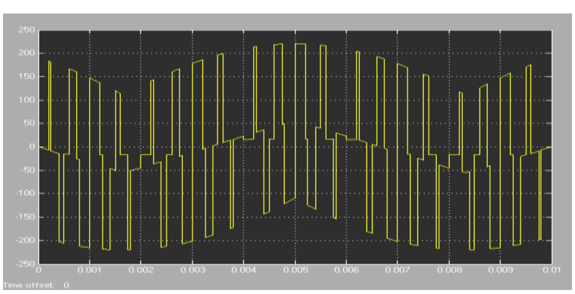


Fig.33: Results taken by Simulink software program

The above figures show the output from the drive that is the input voltage of the AC motor

6. The values of active and reactive power during different movements of cranes 106, 109.

When the cranes make different movements active and reactive power, the generated and consumed power and the value of power factor can be shown on table (2), these values are taken from PLC program of the crane as shown in fig (34):

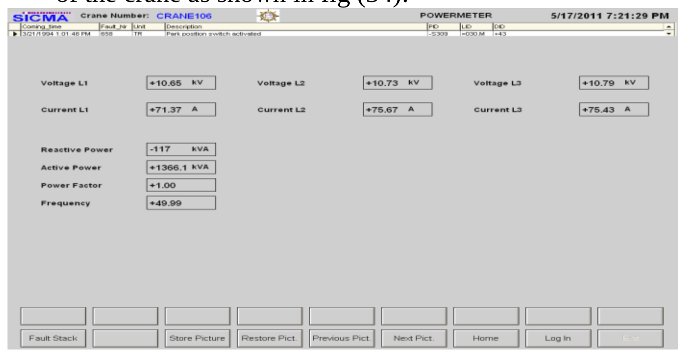


Fig.34: Values from PLC program of the crane

Table (2): Values current, power factor, active and reactive power when the crane makes different movements

motion	**current on phase**			**active and reactive power**		**power factor**
hoist up without container	81 A	85A	88 A	-1539 KVA	-84 KVA	+ 1.00
hoist down without container	71 A	76 A	75 A	+1366 KVA	-117 KVA	+ 1.00
hoist up with 26 ton container	65 A	69 A	70 A	-1240 KVA	-47 KVA	+ 1.00
hoist down with 26 ton container	59 A	62 A	62 A	+1123 KVA	-89 KVA	+ 1.00
moving trolley while hoisting up	85 A	91 A	94 A	-1656 KVA	-111 KVA	+ 1.00
moving trolley while hoisting down	33 A	35 A	34 A	+633 KVA	-29 KVA	+0.86
Boom Up	22 A	24 A	23 A	-406 KVA	+18 KVA	+ 1.00
Boom down	11 A	11 A	10 A	+194 KVA	+20 KVA	+0.98

Average Power factor during operation modes (1 to 8) in table (2) is still high when calculate summation of power factor at equation (12):

Power factor average equal:

$\sum(1+1+1+1+1+0.086+1+0.98)$ / (8) = 0.98 ------ (12)

The trolley motion always consumes power, but the hoist and boom motions generate power when it is descending down and consuming power when it is rising.

The value of harmonic order from deferent converters is shown in fig (35) and table (3):

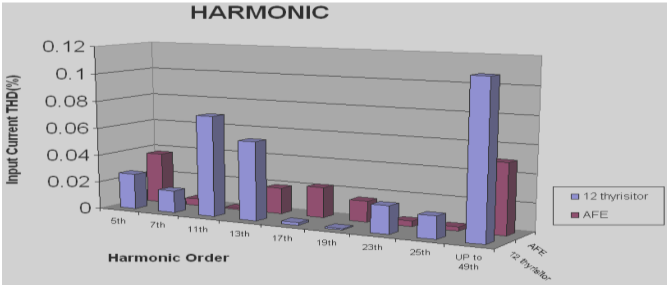


Fig 35: The value of harmonic order

Table (3): Values of harmonic order in deferent converters

Converter Pulses	Harmonic Order								THD
	5	7	11	13	17	19	23	25	Up to 49th
12 thyristor	0.026	0.016	0.073	0.057	0.002	0.001	0.020	0.016	11.0%
AFE	0.037	0.005	0.001	0.019	0.022	0.015	0.004	0.003	5.0%

7. Results dissuasion in medium voltage (11KV) for active and reactive power.

From the previous reading of the consumed power and the value of power factor (cosφ) within 20 day at 24 hour in day.

If assumed all the cranes take the same period of time in the work and make the same motion (hoist motion time , trolley motion time, gantry motion time) in this case value of active and reactive power at all different systems in the cranes can be calculated .so we can compare between value of power consumed in different systems.

In Port Said Container Terminal, it has two electric feeding lines. The first one is (EL-MANTKA EL-HORA) line and the second one is (EL-MHATA EL-GAZIAH) line. The first line feeds seven cranes (101,102,103,104,106,107 and 109) and street lightings. The second line feeds two cranes (105 and 108) beside service building, container refrigerators.

When all cranes are off the value of reactive power for all loads almost unity, because of the power factor correction units in low voltage switchgear (380 - 400 Volt).As a result the resultant reactive power consumed from the substation is the reactive power consumed by the cranes only, In this case we can calculate the reactive power consumption in different systems in the cranes and can also calculate the value of the reactive power in the cranes one by one.

From the previous records in the tables in the cases discussed before the reactive power in the different systems can be calculated. And here is the results shown below:

1-ward Leonard system (system in cranes 101,102) fabricated by LIEBHERR reactive power consumed is equal to 75 kvar.hour.
2-speed control thyristor drive system (system in cranes 105,107 and 108) fabricated by LIEBHERR, this system reactive power consumed is equal to 100 kvar.hour.
3-speed control by thyristor and diode system (system in cranes 103,104) fabricated by Siemens, this system reactive power consumed is equal 50 kvar.hour.
4- Active Front End system (system in cranes 106,109), this system reactive power consumed is almost zero.

8. Conclusion and recommendations

From this study and dissuasion in medium voltage side (11KV) and the results of Active and Reactive Power during different movements of cranes 106, 109 in table (2). The Active Front End System corrects the power factor and consequently reduces the reactive power consumed, reduce the line current and so that losses in Port Said Container Terminal are reduced. Consequently bill of energy is reduced.
Now , it is recommended to use the AFE drive system in all cranes , and that leads to better power factor , less current drawn , and even less losses.

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