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Driving Turbine Via Generator starting as a Motor by LCI & Excitation system

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Dedication:

In the name of Almighty ALLAH for all the benefits it does stop performing in our lives

May peace and salvation be his messenger Mohamed, his family and His companions.

I dedicate this work:

To my parents who supported me throughout my life, may God give them good health and a long life.

To my grandmother, To my brothers and sisters,

To my cousins, cousins, uncles, aunts,

To all who have taught me throughout my school life,

To all who have supported me, directly or indirectly, throughout my life.

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General Introduction :

To start electric motors and control their speed, rheostatic starters, mechanical variators and rotating groups (Ward Leonard in particular) were the first solutions, then static starters and variators have become established in the industry as the modern solution , economical, reliable and maintenance-free.

Since then, power electronics have made considerable progress, and variable frequency drives are being installed more and more with AC motors. These variable speed drives most often use pulse width modulation (PWM) and bipolar insulated gate transistors (IGBT). [1]

All variable speed drives incorporating switching devices (diodes, thyristors, IGBT, etc.) form a non-linear load which generates harmonic currents, sources of wave distortion (drop or disturbance of the voltage) in the electrical network . This degradation of the wave can disturb both the customer's electrical equipment and that of the electrical network if no immunity measure is taken. In addition, harmonic resonances can also appear between variable speed drives and capacitor banks. [1]

Adverse effects can manifest themselves through the premature failure of electrical equipment (overheating of motors, cables and transformers), by the degradation of the insulation of controlled motors or by the interruption of processes (burnt fuses). [1]

The use of variable speed drives offers several advantages [1]:

- Gradual starting of the motors reducing voltage drops in the network and limiting starting currents;
- Improvement of the power factor;
- Increased precision of speed regulation;
- Extension of the service life of the driven equipment;
- Reduction in electricity consumption.

New, more efficient variable speed drives can avoid process interruption in the event of a short-term network disruption.

The purpose of this work is to study and analyze the operating principle of the LS2100e static power starter intended for the progressive start of the alternator of large power installed in the Biskra-oumach power plant while trying to implement a reduced simulation model allowing to describe faithfully the operating modes of the alternator.

The first chapter of this thesis is devoted to a general representation of the simple cycle gas turbine (TG) plant in Biskra-oumach.

The second chapter offers a general presentation and a detailed explanation of the operating principle of the LS2100e static starter and an application of the gas turbine start sequence.

In the third chapter, we discuss about the Load-Commutated-Inverter (LCI) Supplied Synchronous Motor Drives

We end our work with a general conclusion and a bibliographic study.

Chapiter-1

Introduction:

The Biskra-oumach Project will build a single cycle (TG) gas turbine power plant based on the combustion of natural gas in pressurized air and on the expansion of hot burnt gases in a turbine coupled to an alternator with a overall power of 1338 MW at the factory and site condition terminals, which will supply electricity over 4 wilaya networks. The Biskra-oumach single cycle gas turbine power plant will consist of 4 MS – 9001FA single-shaft gas turbines and 2 steam turbines is designed to operate in an installation configured as a single cycle or combined steam cycle unit and gas (STAG) to be supplied by GE.

The power plant is being developed on a 2.5ha land parcel located in Oumache in Biskra Province, Algeria.

It will feature four gas turbines, two steam turbines, four heat recovery steam generators (HRSGs) and two cooling towers.

The project also involves the construction of gas storage facilities, combustion chambers, powerhouses, substations, access roads, parking facilities, transmission lines, and other associated facilities. [1]

The Biskra combined-cycle power project involves the development of a 1,338MW combined-cycle gas turbine (CCGT) power plant in Biskra Province, Algeria.

Also referred to as Oumache power plant, it is being built by Societe Algerienne de Production de l'Electricite (SPE) under the Emergency Power Generation Construction Program, which covers the development of eight CCGT plants in multiple locations in Constantine Province, Algeria.

SPE is an affiliate of Algeria’s national electricity and gas company, Sonelgaz.

The other power plants being developed under the program are Setif, Boumerdes, Naama, Khenchela, Jijel, Djelfa, and Mostaghanem, which will have a combined capacity of 12GW.

The construction of the Biskra combined-cycle power plant began in 2014 and is scheduled to be completed in 2020. [1]

Contractors involved:

The consortium of Daewoo International, Hyundai Engineering & Construction and Hyundai Engineering received the engineering, procurement and construction (EPC) contract for the power plant in February 2014.

“The turbines are equipped with advanced F-class technology for 50Hz application and offer a combined-cycle efficiency of 60% and more than 99% reliability.”

GE was selected as the contractor for supplying gas and steam turbines. The company received a $ 2.7bn contract to deliver turbines and generators for multiple power plants being developed by SPE.

GE is responsible for delivering 26 heavy-duty gas turbines, 12 steam turbines and 38 generators for Sonelgaz.

TERRASOL was contracted to conduct a geotechnical study for the Biskra project. It also provided technical assistance during the construction of the foundations. [1]

The contract for mechanical installation and piping works for Biskra combined-cycle power plant was awarded to ILK construction.

Siveco China was contracted to provide a computerized maintenance management system (CMMS) for the power plant in June 2015.

Macoga received a contract to supply expansion joints for the plant in September 2017. Fabrication of piping spools was completed by Sung il sim.

Hareket was contracted to deliver heavy lifting and transportation services for the project. The company employed Demag CC2800 crawler crane with 600t capacity to lift the HRSG module. [1]

Turbine details:

The Biskra combined-cycle power plant will integrate four GE 9Fseries gas turbines, which are robust and heavy-duty gas turbines designed for operation in challenging environments.

The turbines are equipped with advanced F-class technology for 50Hz application and offer a combined-cycle efficiency of 60% and more than 99% reliability. [1]

Powered by natural gas from local Algerian fields, the turbines will be equipped with the latest dry low NOx (DLN) dual-fuel combustion technology to reduce emissions, extend the maintenance intervals and ensure increased flexibility. [1]

GE D10 series 170MW steam turbines are designed with high-reaction 3-D blading for high, intermediate or low-pressure turbine modules.

The integral covered blades with continuous contact surfaces provide superior damping ability for more mechanical integrity, while the design of the nozzle offers precise control of circular clearances and ensures higher output and efficiency. [1]

I.1 General description of the plant:

I.1.1 Location of the power station:

The power plant is built on a 2.5 hectare plot located 60 km from the center of biskra, 40 km from oumach [1]

Figure I-1 : Biskra Combined cycle power plant

I.1.3 Technical characteristics:

-Turbine :

Manufacturer: GE COMPANY

Power: 4 × 235 MW

Nominal speed: 3000 rpm

Number of compressor stages 18

- Alternator:

Type: 324LU

Manufacturer: GE COMPANY

Apparent power: 308,000 KVA

Active power: 261,800 KW

Power factor: 0.85

Frequency: 50Hz

Number of pole pairs: 2P = 2

Nominal speed: 3000 rpm

Coupling: Star (Y)

Insulation class: F

Weight: 278 374 kg

- Exciter:

Type: Static

Active power: 1146 KW

Direct current: 1857 A

Voltage: 617 V

Hydrogen gas pressure: 413.7 kPa

- Main transformer:

Manufacturer: Balikesir Elektromekanik Sanayi Tesisleri (BEST)

Type: THREE-PHASE UNDERWATER IN OIL

Power: 239/315 MVA

Cooling type: ONAN / ONAF

Voltage ratio: 220/15 KV

Current Ratio: 862.7 / 12,124.4 A

Frequency: 50 Hz

Weight: 284.0 t

– Withdrawal transformer:

Manufacturer: Balikesir Elektromekanik Sanayi Tesisleri (BEST)

Type: THREE-PHASE UNDERWATER IN OIL

Power: 16/20 MVA

Voltage ratio: 15 / 6.6 KV

Current ratio: 769.8 / 1749.5 A

Frequency: 50Hz

Weight: 38.5 t

- Fuel:

Main fuel:

natural gas

Emergency fuel:

diesel Number of diesel tanks: 2 × 14500 3

I.1.3 Description of the different groups of the main components:

The installation of the Biskra gas turbine power plant includes all the systems, components and devices necessary to ensure safe and profitable operation of the installation. The main components are A) Main machine groups: The main machine groups are responsible for all energy conversions and constitute the nucleus of the power plant. They include the three alternators and the (gas) turbine because of their importance, gave their no to the power plant.

Figure I-2 : Turbine generator group

B) Distribution network and systems:

The network and the distribution systems allow the electrical connection of the main groups of machines to the electrical network, thus allowing the transport of energy outside the installation. Network and distribution system components include the following: [3] [4]

- Switching equipment
- Measuring instruments and equipment
- Distributors
- Decentralized panels and cabinets
- Power transformers, etc.

C) Heavy machinery:

Heavy machinery supports electrical installation through specialized services such as emergency electrical power supply. The main components of heavy machinery are the seven standby diesel engines.

D) Fuel supply and residue disposal equipment:

The fuel supply and residue disposal equipment stores, processes, distributes and supplies fuel supply energy to the main machine groups. In addition, they evacuate, treat and condition fuel residues for disposal [3] [4]

The components of the fuel supply (liquid, gaseous) and the elimination of residues include the following elements:

- Unloading equipment
- Storage park
- Pumping system
- Distribution piping network
- Agent heating system
- Drying system
- Heating system
- Main pressure reduction station
- Mechanical cleaning and purification equipment
- Main pressure increase station
- Residue disposal system

E) Instrumentation and control equipment:

The instrumentation and control equipment is responsible for the operation, control and supervision of the entire gas turbine installation, that is:

A) The electrical room (EROOMS):

- Machine Control Center (MCC)
- MARK VI turbine protection

- Generator protection
- UPS: inverter
- TP protection (main transformer)
- T52 protection (line circuit breaker)
- Protection G52 (group circuit breaker)
- Fire protection and control cabinet

B) electrical and control building:

- MCC: TG motor start
- MCC: common auxiliary motor start
- TG command and control pipette
- Rectifiers, inverters

Figure I-3: The electrical room (EROOMS)

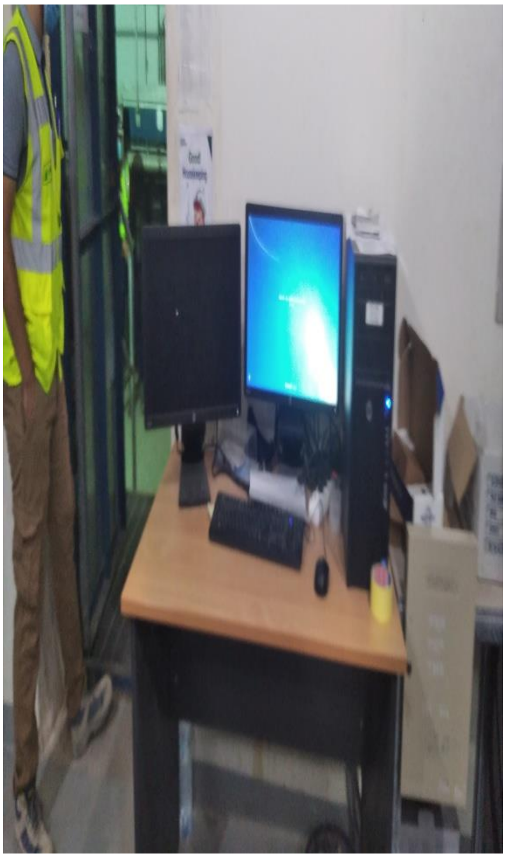


Figure I-4: electrical and control building

F) Auxiliary systems:

The auxiliary systems support the power plant with common services. The main components of the auxiliary systems are: - Stationary compressed air supply - Fire-fighting building - Anti intrusion - Workshops, warehouses, laboratory equipment and staff facilities

I.2 Description of operation:

The supply of electrical energy from the Biskra gas turbine installation involves the use of a gas turbine, an alternator, an exciter, a bushing for the alternator, a circuit breaker for the alternator and a booster transformer for the alternator. The role of each of these elements is described briefly below.

I.2.1 Gas turbine:

A) General:

The MS – 9001FA single-shaft gas turbine is designed to operate in an installation configured as a single cycle unit or a combined cycle with steam and gas. [5] The gas turbine consists of three elementary parts

- **Compressor:**

Inside the compressor body are the variable opening guide vanes, the different stages of rotor and stator vanes and the output guide vanes. In the compressor, the air is confined in the space between the rotor and the stator where it is compressed in stages by a series of alternating rotating (rotor) and fixed (stator) aerodynamic blades. The rotor blades give the force necessary to compress the air on each stage and the stator blades guide the air so that it arrives on the next stage at the right angle. Compressed air leaves the compressor through the exhaust body to the combustion chambers. Air is also extracted from the compressor for cooling the turbine and controlling the pulsations at start-up. [5]

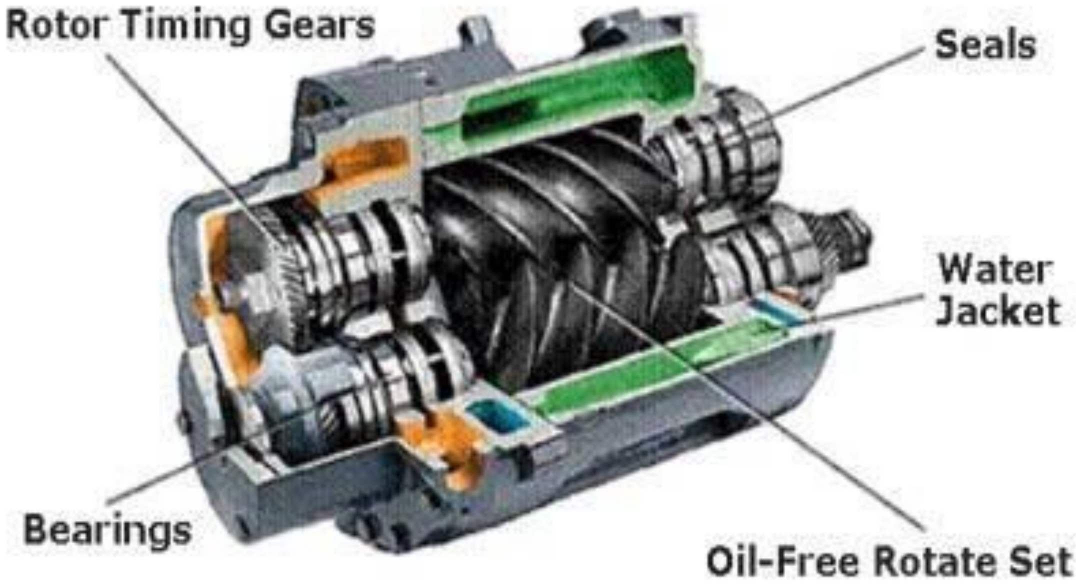
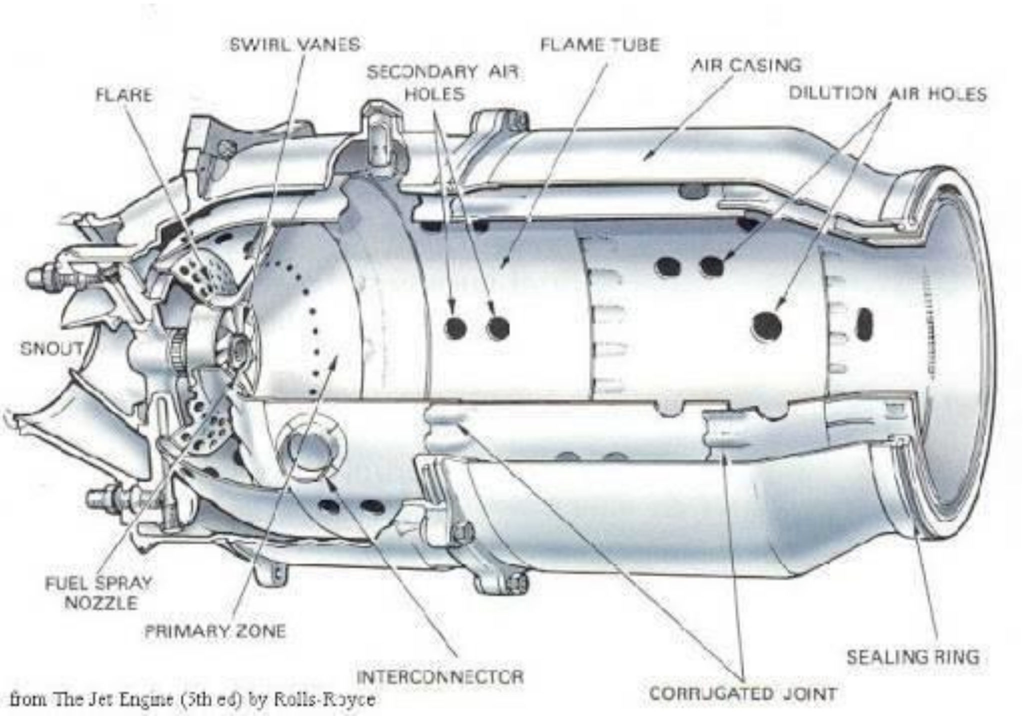


Figure I-5 : compressor section

- **Combustion chamber:**

The combustion chamber and equipped with eighteen reverse flow type burners installed around the periphery of the compressor exhaust body. [5]

The hot gases, released from the ignited fuel within the combustion chambers, circulate in the direction of the turbine through the transition parts cooled by contact.



from The Jet Engine (5th ed) by Rolls-Royce

Figure I-6 : Combustion Chamber

• Turbine:

In which the energy contained in the high temperature pressurized gas produced by the compressor and combustion sections is converted into mechanical energy. The MS9001FA gas turbine includes the turbine rotor, body, exhaust box, exhaust diffuser, injectors, and tires [6].

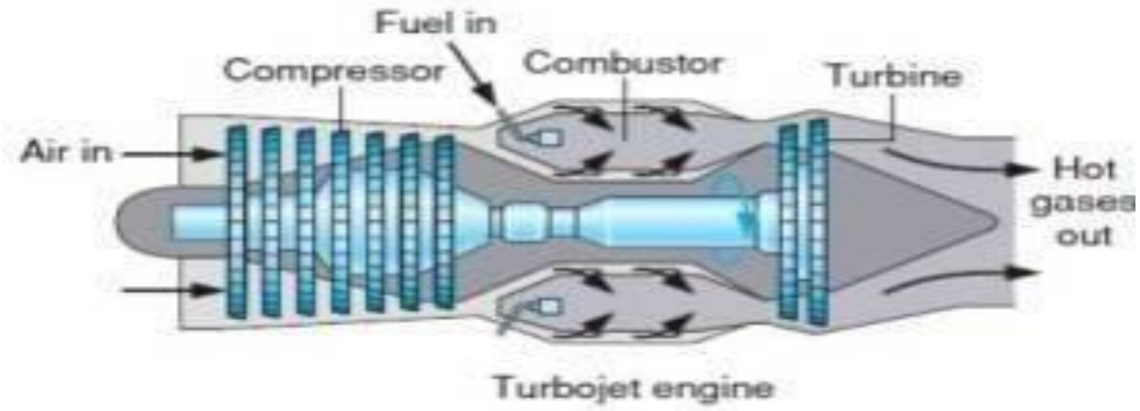


Figure I-7 : Turbine section

B) Function:

The cold air drawn from the environment outside the site is compressed and heated by passing through the compressor. Carrying out this phase requires consuming a certain amount of mechanical energy, by subtracting it from the kinetic energy of the turbine through the rotor.

Inside the combustion chamber, the chemical reaction between air and fuel produces an increase in temperature and pressure. Then, in this reaction the calorific value of the fuel is transformed into thermal energy.

Finally, passing through the turbine, the hot gases spread, their pressure and their temperature decreases accordingly. This phase produces a large amount of mechanical energy, part of which is required by the compressor, and the most important part will be directed to the network through the generator and the main transformer. [7]

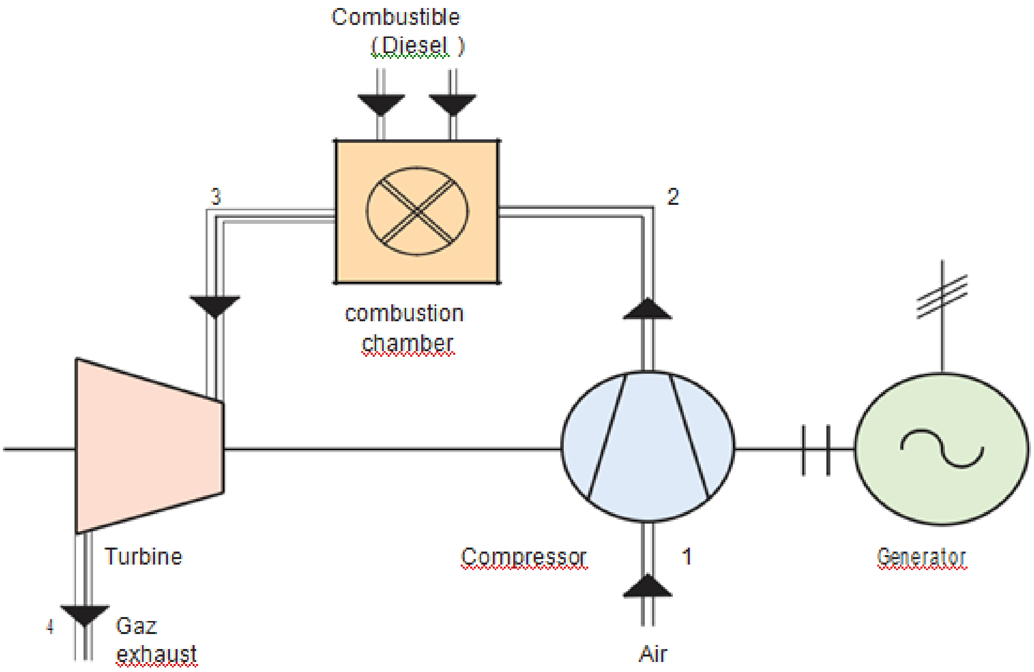


Figure I-8 : Schematic representation of a group's air gas circuit gas turbine

I.2.2 Alternator:

A) Operation:

The rotor is a magnet that creates a rotating magnetic field in the machine through the excitation of the field winding, which is often called the winding of the rotor to facilitate understanding. It is necessary to adjust the intensity of the magnetic field according to the electrical charge of the alternator to maintain synchronization between the alternator and the network and so that the alternator voltage and the reactive power supplied to the network are within defined limits.

For this, a direct current (called excitation current) must pass in the field winding of the rotor. The excitation current is in turn controlled by the automatic voltage regulation (AVR) equipment which controls the voltage at the alternator terminals and the flow of reactive power to the network. [3]

I.2.3 EX2100e exciter:

The EX2100e excitation produces the field excitation current to control the AC voltage across the alternator and supports both static excitation systems and brushless and Alterrex rotary exciters. [3] [8]

I.2.4 Alternator bar ducts:

The alternator bar ducts provide the connection for delivering electrical energy from the alternator to the outside. The bar ducts are mounted on the stator housing of the alternator and they receive the high voltage delivered by the stator windings. [3]

I.2.5 Group circuit breaker:

The alternator circuit breaker represents the electrical connection between the alternator bushings and the main transformer. [3]

I.2.6 Power transformer:

The power transformer is used to adapt the output voltage of the alternator to the mains voltage. [3]

Conclusion:

In this first chapter we have tried to briefly present the new oumche-Biskra gas turbine power plant, and we have cited some basic equipment making up the power plant such as the gas turbine, the alternator and their operation.

Chapiter-2

Starting System :

GAS TURBINE STATIC START SYSTEM :

System Function and Design Requirements :

Power for startup of the gas turbine is provided by the static start system. The static start system provides variable frequency voltage and current to the generator, in this way the generator serves as the starting motor required for starting the gas turbine. [8]

The static start system consists of the following major com-ponents:

Load Commutated Inverter (LCI)

Isolation Transformer

LCI Disconnect Switch

Slow Roll Motor (Turning Gear)

The turning gear provides the power necessary to breakaway and rotate the turbine prior to turbine start and also to rotate the shafting after turbine shutdown to avoid deformation of its shafting.

The turning gear system consists of an induction motor, reduction gears, SSS clutch, electrical isolation, and flexible coupling.

The turning gear will breakaway the turbine and slow roll at 5 to 7 rpm. In the event of power failure the turning gear is equipped with a feature for manual turning of the rotor system. [8]

Lubricating oil for the reduction gears is self–contained. Lubrication of the SSS clutch and output shaft bearings requires continuous oil supply from the main lube oil system.

The SSS clutch is a positive tooth type overrunning clutch which is self-engaging in the breakaway or turning mode and overruns whenever the turbine/generator shafting exceeds the turning gear drive speed.

The insulated flexible coupling allows for angular and parallel misalignment as well as allowing for gen-erator shaft axial expansion. [8]

Operation :

On a start signal, the lift oil pumps are started to lift the stationary rotor off of the bearing surfaces. The bearing pressure lift system must be operating prior to energizing the turning gear. This significantly reduces the amount of starting and break–away torque required for the machines and minimizes bearing damage during startup. Breakaway of the rotor system is accomplished by energizing the turning gear induction motor. A double reduction worm gear reducer is furnished with a hollow shaft in which the SSS clutch is mounted. Automatic engagement of the SSS clutch provides direct power transmission to the rotor system. The turning gear will rotate the rotor system to 5 to 7 rpm. As the static starter begins the starting

sequence and accelerates the rotor the SSS clutch will automatically disengage the turning gear from the turbine rotor. [8]

The static starter will begin operation in the “pulsed” mode, changing to the “load commutated” mode as soon as possible. The static starter will supply the variable frequency stator (armature) current re-quired by the generator to operate as a synchronous motor and drive the gas turbine. The static starter will control the excitation system during static starting to regulate the field (rotor) current as required to maintain the required flux and generator voltage. The static start system operates to accelerate the tur-bine to 25 to 30 percent of rated speed to purge the system for several minutes. At the end of the purge period the LCI removes power from the generator allowing the unit to coast down to approximately 15% speed and the turbine is fired and then accelerated to a self sustaining speed of about 90%. The static starter currents will be reduced as required until the starting means is no longer required. After self sus-taining speed is accomplished the control system will load and synchronize the gas turbine generator. Operation of the neutral ground and stator disconnect switches is automatically controlled during the starting process. [8]

Upon turbine shutdown, as the turbine decelerates to below turning gear speed (5 to 7 rpm), the SSS clutch engages if the turning motor is energized to provide slow roll rotor cooldown. This cooldown con-tinues until proper gas turbine wheelspace temperatures drop to ambient. [8]

In the event of a power outage when rotor turning is required, a manual turning assembly is provided to turn the rotor. This manual turning feature can also be used for borescope inspection of the gas turbine. [8]

The turning gear system is sized to provide breakaway of the shafting system with the bearing pressure lift system operating on both the gas turbine and generator for manual and motor turning of the rotor train. [8]

Purpose of LCI:

Use the Generator as a Motor to drive the turbine to self sustaining speed

Substantial savings of energy and maintenance costs

Smoother running results in

– higher productivity

– longer plant life

Reasons for using LCI:

Efficiency

- Compressors, fans and pumps run at their optimum operating point.
- Substantial energy savings

Reliability

- Mechanical flow control devices as potential source of failures are eliminated.
- «Softer» control reduces wear on motor and driven plant.

Maintenance

- Less stress and wear reduces the maintenance requirement.
- Mean time to repair typically <1 hour

Emissions

- Electric drives avoid emissions.
- Noise reduced to the minimum possible.

Better process control

- greater accuracy
- smooth control at low flow rates
- wider range of control
- faster response with greater stability
- reduced production waste and higher quality
- set-points quickly reached and therefore shorter production times
- renowned reliability and adaptability

Soft starting

- less mechanical stress on motor and driven plant
- minimum repercussions on the supply system
- reduced temperature rise while the motor is accelerating
- no need of pony motors and clutches
- starting of very large motors and generators. [18]

Typical applications:

Speed control and soft starting of

– fans and pumps

– high-speed compressors

– reciprocating compressors

– wind tunnel blowers

– blast furnace blowers

– rolling mills

– extruders

– marine propulsion systems

– test bays. [18]

Figure II-1 : Boiler feed pumps in a thermal power plant driven by MEGADRIVE-LCI

Figure II-2 :Compressor hall with 3 reciprocating compressors equipped with MEGADRIVE-LCI in a natural gas pumping station

Figure II-3 :Polyethylene extruder drive with MEGADRIVE-LCI

Figure II-4 :Wire block drive with MEGADRIVE-LCI

Benefits of LCI vs. Cranking Motor:

-Shorter Drive Train, replaces cranking motor/gear

-One LCI can start multiple Gas Turbines

-Less moving parts, lower maintenance

LCI and Mechanical Start drive trains:

Mechanical Start:

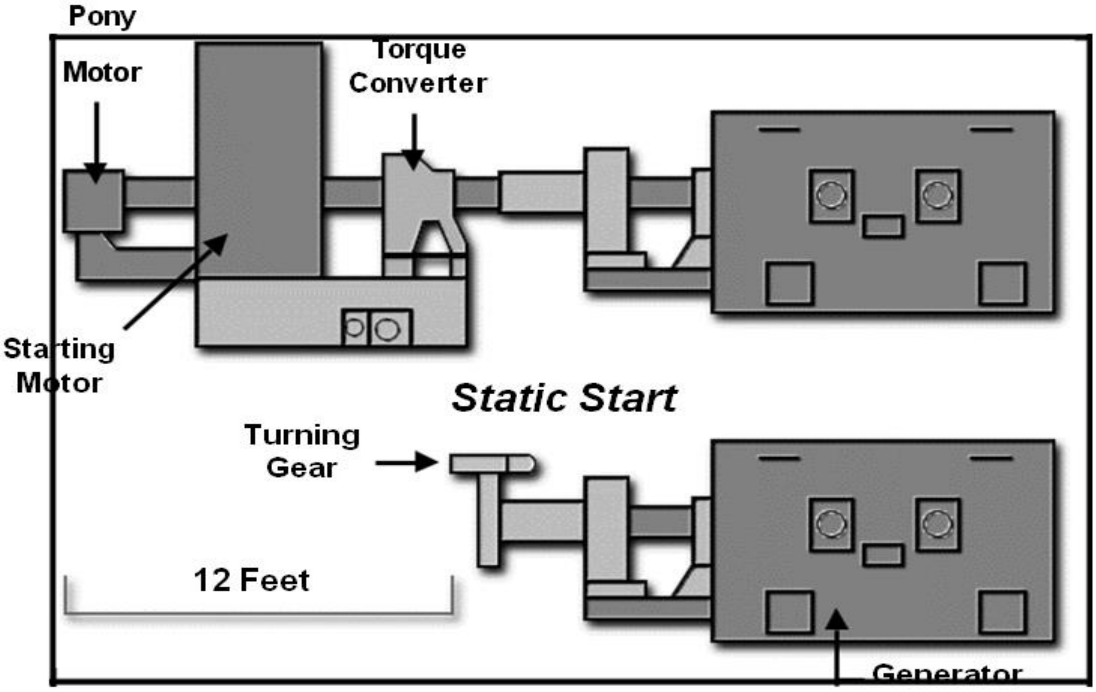


Figure II-5 : Mechanical Start Drive Trains

2 LCI's , 4 Turbine Generators:

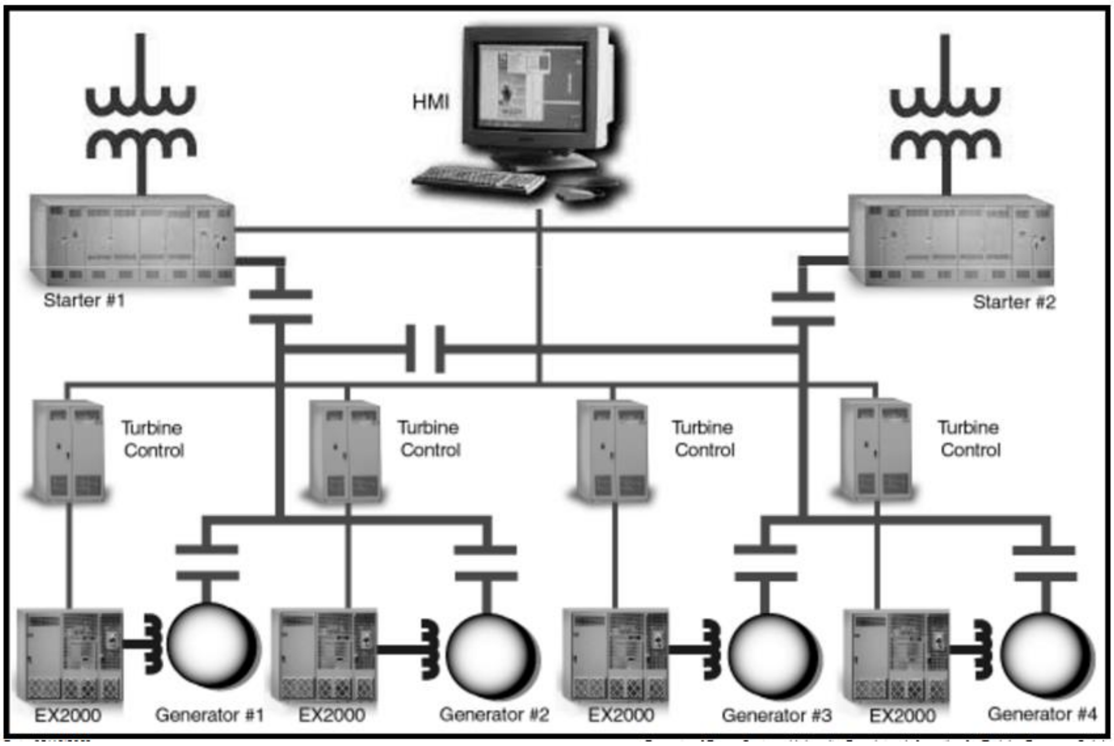


Figure II-6 : LCI cycle combine control with 4 Turbine Generators

Theory of Operation :

-The LCI outputs power to the machine stator to create a rotating magnetic field in the stator

-The exciter magnetizes the machine rotor

-The rotating stator magnet pulls the rotor

-The speed of the stator magnet is adjustable and determines the speed of the rotating parts.[8]

Introduction:

The LS2100e static starter is an adjustable speed AC drive system specially designed to start a gas turbo alternator group. The static starter supplies variable frequency current to the alternator stator as the turbine accelerates to full speed. [8]

This chapter presents the static starter and provides a general presentation of the product. And we describe the operation of the static starter system LS2100e. [8]

The LS2100 Static Starter is an adjustable speed ac drive system specifically designed to start a gas turbine-generator set. By operating the generator as a synchronous motor, the Static Starter accelerates the turbine set according to a specific speed profile that provides optimum starting conditions for the gas turbine. The LS2100 eliminates the need for separate starting hardware, such as an electric motor or diesel engine, torque converters, and associated auxiliary equipment, thus opening up critical space around the turbine base.[8]

The LS2100 has a digital control that interfaces seamlessly with the Mark VI gas turbine control, the EX2100 excitation control, the Human-Machine Interface (HMI), and the PI Historian. These devices communicate with each other over an Ethernet®- based data highway to form a fully integrated control system. The GE Control Systems Toolbox (toolbox) is used to configure the LS2100 control. This is the same toolbox used to configure the Mark VI gas turbine control and EX2100 excitation control. [8]

LS2100e:

The LS2100e controller operates the alternator as a synchronous motor to accelerate the gas turbine group according to a specific speed profile which provides optimal starting conditions. The LS2100e controller eliminates the need for a separate starter system (electric or diesel engine), torque converters and associated auxiliary equipment, thereby significantly freeing up space around the turbine base.

The LS2100e has a digital controller that easily connects to various GE Energy excitation and turbine controllers, including the human-machine interface and Historian products. These devices communicate with each other via an Ethernet UDH (unit data highway) network to form a fully integrated control system. The ToolboxST application used to configure the LS2100e is the same application used to configure the gas turbine and excitation control devices.

The LS2100e power converter is available in two nominal powers: 8.5 and 14 MVA. [9]

Both systems are designed to best match the starting power requirements of the two sets of Type 7 and 9 gas turbine alternator. The system architecture supports LAN Ethernet communications (UDH). with other GE Energy equipment, including the ToolboxST application, the EX2100e excitation control, the Mark * VIe turbine control and the HMI interface (operator interface). [9]

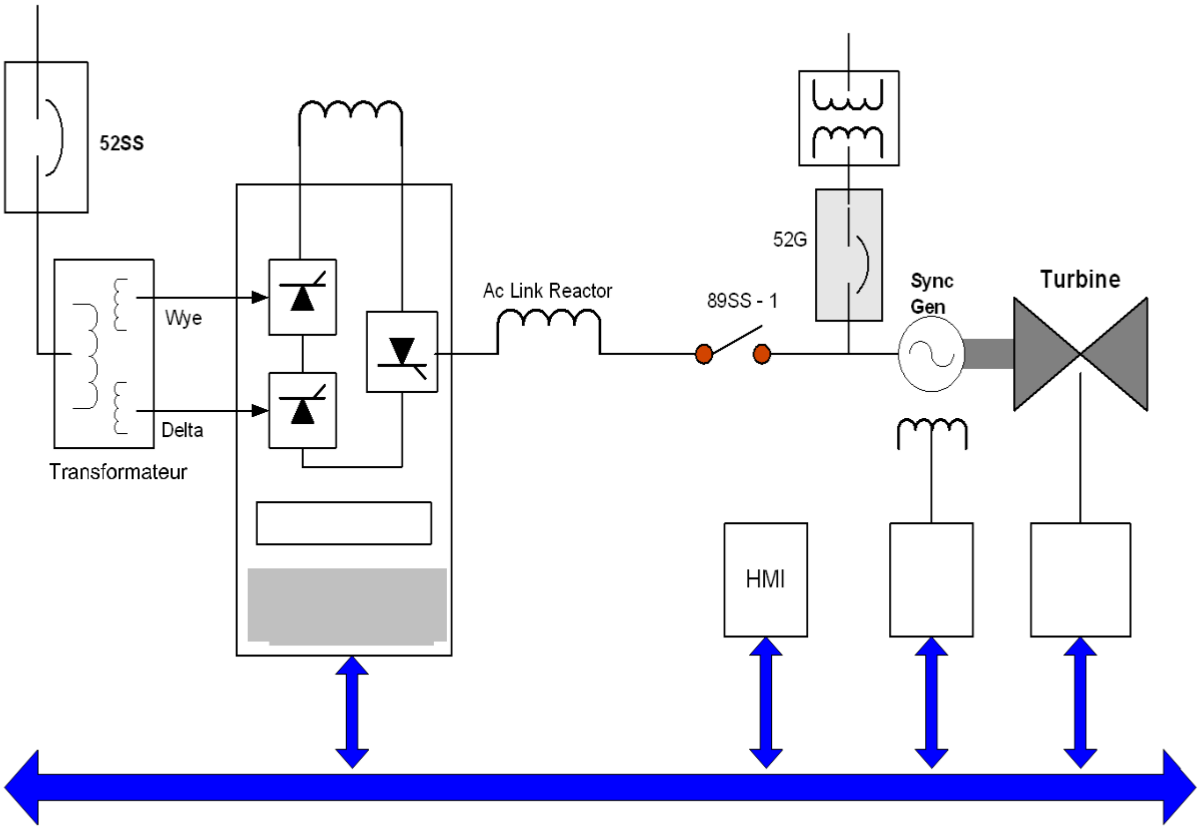


Figure II-7 : Presentation of the LS2100e controller

The LS2100 static starter provides variable frequency AC power to the alternator stator, which causes the alternator to operate as a synchronous motor during the start sequence. The static starter control also provides the voltage reference, allowing it to control the alternator's excitation field and operate as a synchronous motor. At a speed of approximately 90%, the LS2100e disengages and no longer rotates during normal operation of the alternator. [10] The alternator start-up results from the phase controlling the output of the silicon current rectifier (SCR) bridges. The controller's digital regulators generate SCR ignition signals. The controller regulates the output voltage to produce a variable frequency that allows smooth acceleration of the alternator. The following figure shows the interfaces of the power source, or electrical network, the source switchgear (52SS), the load switchgear (89SS), the control module, the power conversion module (PCM) and cooling system. The interfaces of the alternator control panel and the turbine control panel are also illustrated.

II.1.1 System Architecture :

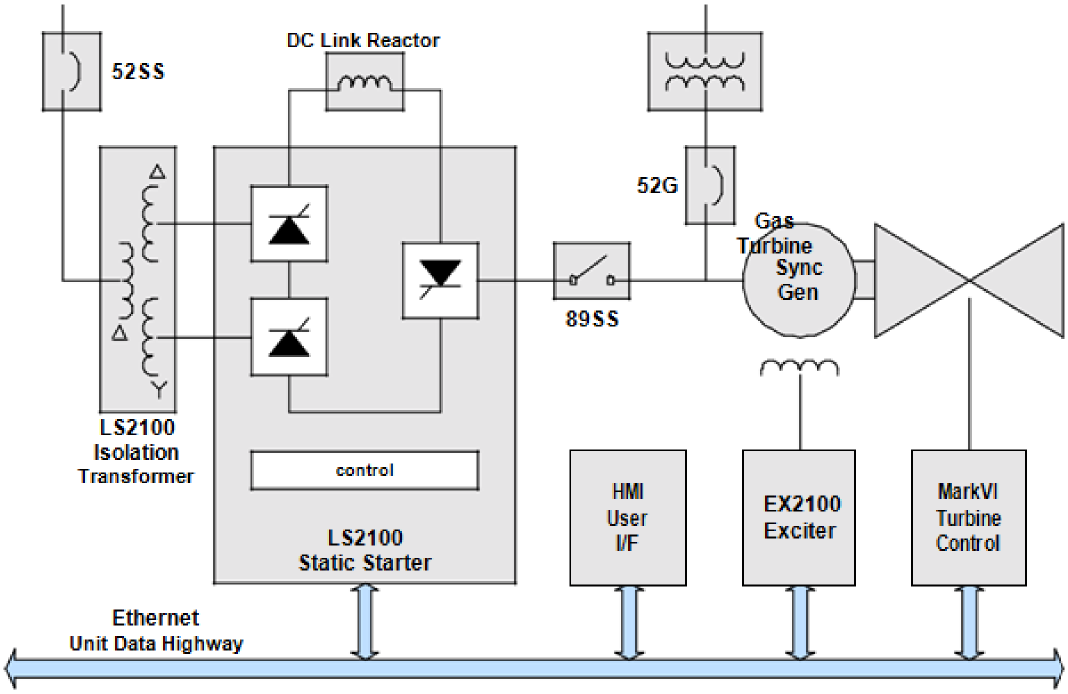


Figure II-8 :Static Starter System

A simplified one-line diagram for the Static Starter system is shown in following figure

Power magnetics are used in the system to provide isolation, voltage transformation, and impedance. These include:

The isolation transformer feeds 3-phase ac input power to the Static Starter power converters. The transformer provides isolation from the ac system bus and provides the correct voltage and phasing to the static converters.

The dc link reactor is an air core inductor that provides inductance to smooth the current delivered by the static power converters.

Various circuit breakers and motor operated disconnect switches are used in the system to make the appropriate power connects required for a static start operation. The 52SS is a circuit breaker used to connect the primary side of the LS2100 isolation transformer to the system auxiliary bus. Depending on the application, either the Static Starter or the Customer DCS controls this

breaker and it must be closed during starting. It may optionally be left closed after the start is complete.

The 89SS is a motor operated disconnect switch used to connect the Static Starter load inverter output bus to the generator stator. The MarkVI controls this switch and it must be closed during starting and opened after the start is complete.

The 52G is an optional circuit breaker used to connect the generator stator to the system bus. The Mark VI Turbine Control controls this breaker and it must be open during startup.

The architecture of the LS2100e control system supports communication from the Ethernet Local Area Network (LAN) Unit Data Highway (UDH). The following drawing shows the network or the power supply, the switchgear cabinet for electrical equipment (52SS), the load cabinet for electrical equipment (89SS), the control module, and the electrical conversion module. (PCM), as well as the interfaces to the HMI, the exciter and the Mark * VIe turbine control panel (TCP). (Figure II.1)

The magnetic electricity of the LS2100e control provides insulation, voltage transformation, impedance, including:

- The isolation transformer: it supplies the three-phase AC input power to the LS2100e control electricity converters by isolating it from the AC system bus and provides the static converters with the correct voltage and phasing.

- The in-line DC reactor: it is an air inductor which provides an inductor to regulate the current distributed by the static electricity converters.

The LS2100e control uses various motor and circuit breaker disconnectors to make the proper electrical connections necessary for operation. These are supplied separately from the LS2100e control and include: The 52SS, G52, 89SS, and 89MD. [11]

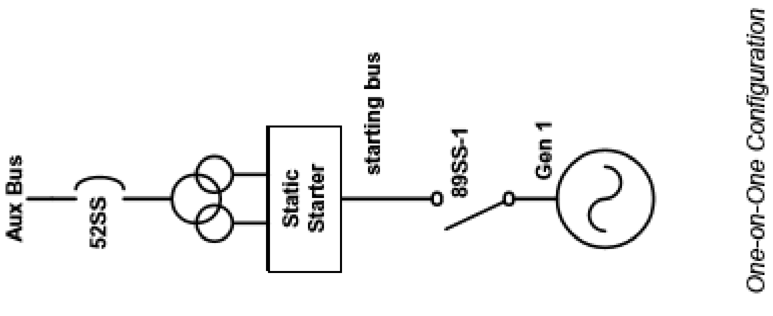
The 52SS circuit breaker is used to connect the primary side of the isolation transformer of the LS2100e control to the system auxiliary bus. Depending on the application, either the LS2100e command or the customer's distributed control system (DCS) controls the 52SS circuit breaker. It must be closed at start-up and can remain closed (optional) after start-up. The 89SS is a motor disconnector used to connect the load inverter output bus of the static starter to the stator of the alternator. The turbine control system controls this disconnector. The 89SS disconnector must be closed at start-up and open after start-up. The 52G is an optional circuit breaker used to connect the alternator stator to the system bus. The turbine control system controls this circuit breaker and it must be open during start-up. The 89ND disconnect switch is used to disconnect the neutral grounding device from the alternator during static start-up mode. [10], [11]

II.1.2 System Configurations :

The starting system configuration should be chosen to provide the best optimization of cost and starting availability. The following sections illustrate the various starting system configurations that are available and define the benefits associated with each.

One Starter for One Turbine

In this starting system configuration, one Static Starter is responsible for starting only one turbine-generator set. This is the simplest system, both in terms of physical layout and implementation. There is a single starting bus associated with the one Static Starter. The generator has an 89SS motor operated switch that is used to connect the generator stator to the starting bus. The one-line diagram for this "oneon-one" configuration is shown in the



following

Figure II-9: the one-on-one configuration has the advantage of simplicity. There are no provisions for redundancy with this system.

II.1.3 Presentation of the LS2100e components:

Cabinets :

Figure II-10: MVA Static Starter Enclosure

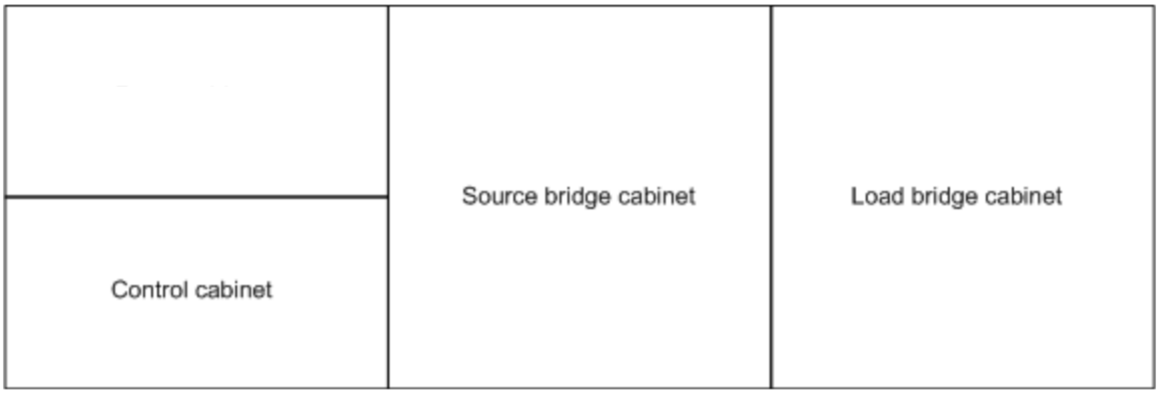


Figure II-11: Top view of the 14 MVA system

Some versions of the LS2100e static start control include an insulation distance of 127 mm between the power conversion cabinets and the control and pump cabinets [12]. This space simplifies the addition of a protective plate or wall to protect personnel performing maintenance on control or pump cabinets against the risks associated with electric arc flashes in the power converter. In addition to the assembly shown, the LS2100e controls are also available as an upgrade to the separate digital front pillar (DFE) controls to enhance the existing static starter installations. In addition, the controls and cabinets of the LS2100e cooling system are available with a separation of the electrical conversion cabinets to facilitate a barrier or wall to the control room installations. LS2100e control equipment consists of three cabinets [12]:

A) Control cabinet:

The LS2100e control cabinet has two doors mounted on hinges accessible from the front, which are kept closed by four locked screws, which require a tool to open it and a single point handle. The handle is equipped with a lockable padlock to lock the cover so that it remains in the closed position. The control cabinet contains the following components:

- Control supply circuit breaker
- Control power transformer and power supplies
- Standalone version B of the universal controller (UCSB)
- Panel mounted relays
- LS2100e Static Starter I / O terminal board (LSTB) (I / O terminal block of the LS2100e start control (LSTB])
- LS2100e Static Starter gating interface board (LS2100e static start trigger interface board)
- Power supply and connection electrical input supply (XOVR)
- Customer connection blocks

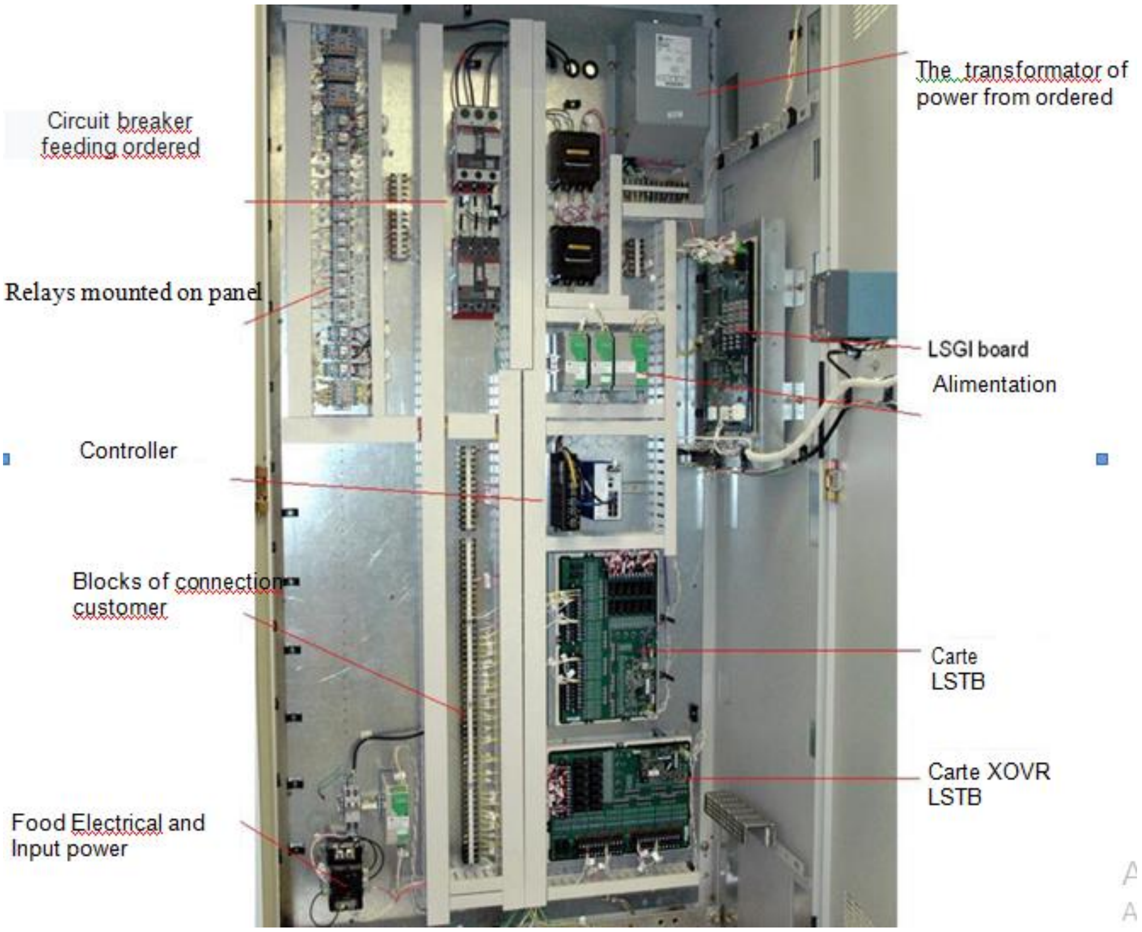


Figure II-12: The LS2100e connection control cabinet (interior)

A) Control Cabinet:

The control cabinet has two front access hinged doors held in the closed position with a three-point latch and a handle that can be padlocked. Located inside the control cabinet are [17] :

- Control power circuit breaker
- Control power transformer and power supply
- VME card rack
- Panel mounted relays
- I/O terminal boards
- VersaMax I/O modules
- Customer terminal boards

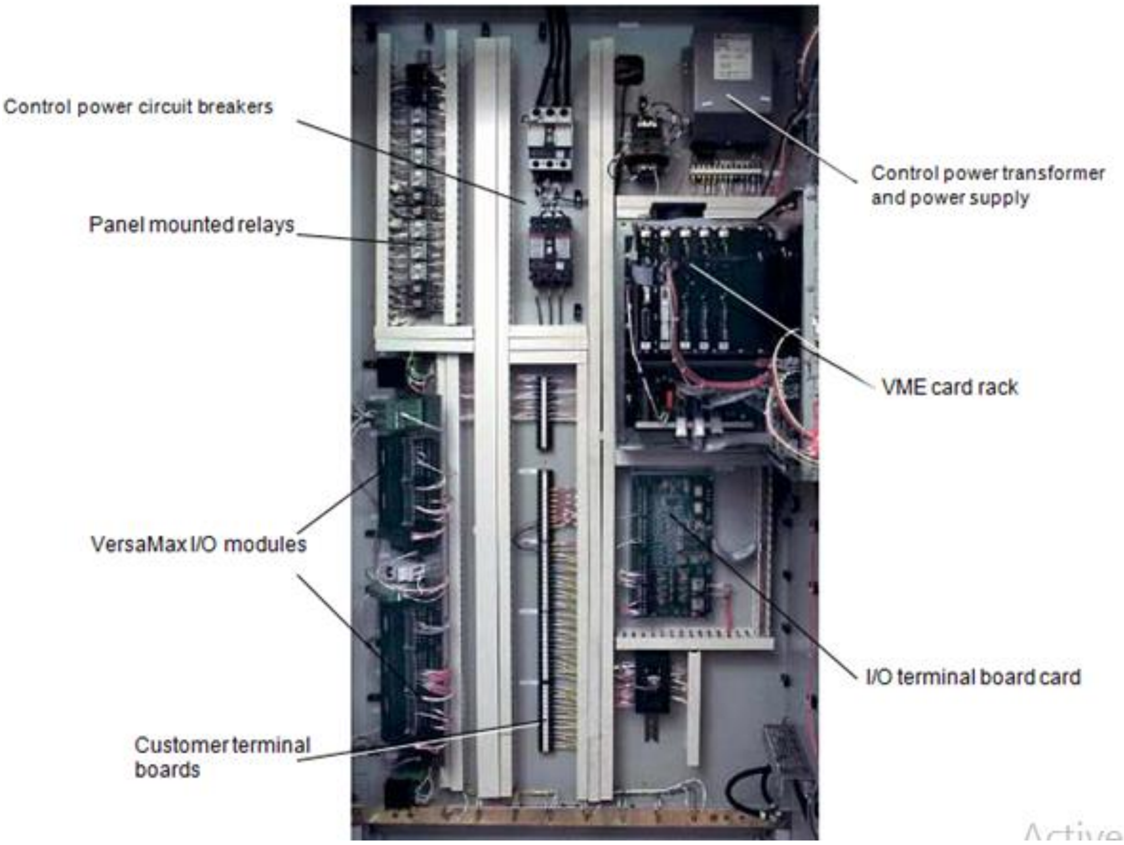


Figure II-13: The LS2100e Control Cabinet

B)Cooling System Cabinet :

The cooling system cabinet is located behind the control cabinet and is accessed from the rear of the lineup. The cabinet has two hinged doors that require a tool for opening and are equipped with a padlock hasp for locking in the closed position. Located inside the cooling system cabinet are [17] :

- Reservoir
- Deionizer
- Filter
- Pumps (2)
- Temperature regulating valve
- Pressure switch and pressure gauge
- Resistivity / temperature sensor
- Level switches

The advantages of cooling sys:

- simplicity
- overload capability for short duty cycles
- permits converters to be installed where cooling water is not available
- space-saving layout
- losses easily conveyed from control room
- higher ambient temperature permissible
- less noise

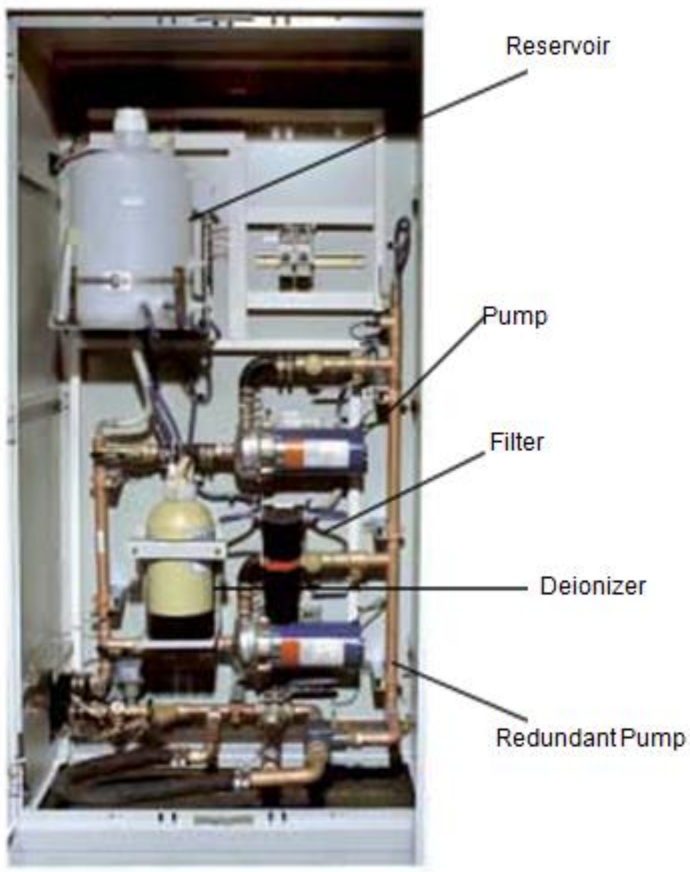


Figure II-14 : *Cooling System Cabinet*

C) Power conversion cabinets:

Electricity conversion cabinets have hinged covers which must be opened by means of a tool and are fitted with a lockable padlock to lock the cover so that it remains in the closed position. The panels welded to the cabinet cover the rear sections, access of which is necessary only for high voltage bus connections. Here is what is in the electrical conversion cabinets [17] :

Source thyristor converters

Source ac line filters

Load thyristor converter

Load ac line filter

FGPA gate pulse amplifier boards

FHVA/B high voltage gate interface boards

NATO voltage feedback boards

FCSA current feedback boards

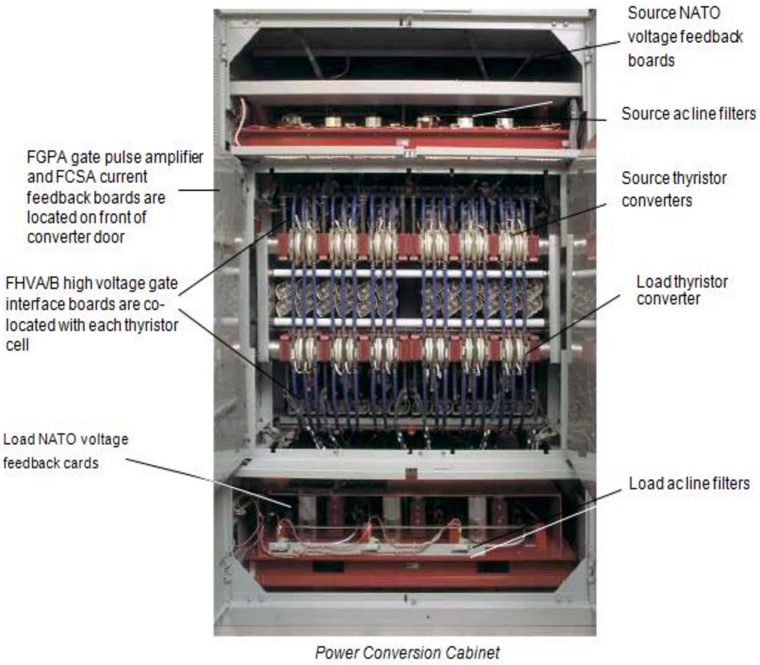


Figure II-11: 14 MVA power conversion cabinet

Power Converter :

The Static Starter power converter consists of two series connected line-commutated phase controlled thyristor source converters that feed a load-commutated thyristor load inverter through a dc link reactor [17]

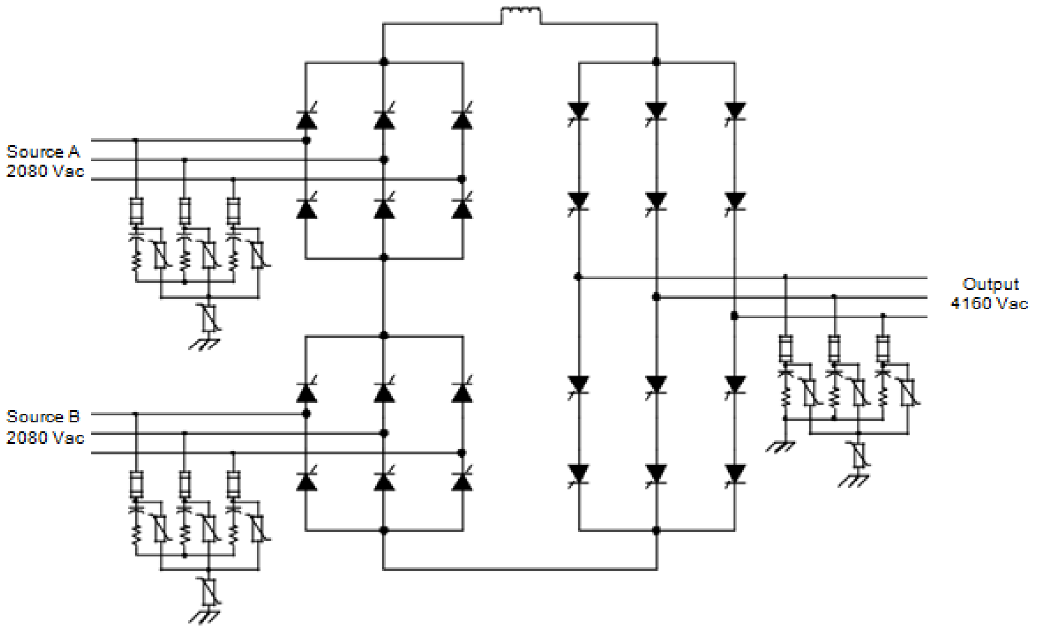


Figure II-16:8.5 MVA Power Circuit One-Line

The source converter gating is digitally controlled to produce the required current through the dc link and the load. The dc link reactor is sized to keep the dc link current continuous over the system's operating range. The load inverter gating is digitally controlled to produce a variable frequency ac output current to the generator stator terminals [17]

D) control equipment:

The UCSB controller contains all the protection and control functions for the LS2100e control. It communicates with the control circuit boards via a point-to-point high speed serial link (HSSL). LSGI communicates with circuit boards in the power conversion cabinet to produce periodic trigger signals for the thyristors and to collect status, current, and voltage feedback. LS2100e control circuit boards:

Carte	**Lieu**	**Description**
UCSB	Wardrobe ordered	Customizable application control panel, network interface and signal processor control digital
LSGI	Wardrobe ordered	Periodic trip communication card
LSTB	Wardrobe ordered	I / O interface card
HSLA	Wardrobe conversion feed	High-speed serial Link interface board high speed serial link)
FGPA	Wardrobe conversion feed	Trigger Pulse Boosting Card
FHVA	Wardrobe conversion feed	High voltage door interface card
FHVB	Wardrobe Conversion feed	High voltage door interface card
NATO	Wardrobe feed conversion	Voltage reaction card

FCSA	Wardrobe feed conversion	Current feedback card

Figure II-17:control circuit boards

II.2 Operating principle of the LS2100e static starter:

The LS2100e control equipment works the same for 8.5 MVA and 14 MVA static starters [13]. The two ratings differ in the number of power converter modules and power converter cabinets supplied. The LS2100e consists of the following basic components :

- Power conversion module (PCM)
- Source bridge line filter
- Load bridge line filter
- Cooling pumps
- Carbon filter
- Deionization cartridge
- Resistivity monitor
- Controllers and I / O cards
- Control power supplies
- Diagnostic interface (touch screen) (optional)

The following equipment is mounted separately from the LS2100e:

- DC online reactor
- AC source disconnector (52SS)
- Load disconnector (89 MD)
- Heat exchanger (choice between water-water and water-air)
- Alternator disconnector (89SS)
- AC line reactance coils (optional)
- Control power protection fuses
- ToolboxST application

The LS2100e is a static control system with adjustable frequency for synchronous machines using the technology of the self-piloted inverter (LCI -Load Commutated Inverter). It uses application-specific microprocessor-based software to regulate the speed of an alternator. The static starter control comprises three cabinets [12]:

- Power conversion cabinet
- Control cabinet
- Pump cabinet

The power conversion cabinet contains the electronic components that make up the power converter. The power converter is made up of a source bridge

which supplies a load bridge via a DC link reactance coil. A transformer isolates the LS2100e from the AC system bar and delivers the proper voltage across the rectifier. The internal impedance of the separation transformer limits the extent of possible downstream busbar failures. The source bridge is a bridge

A line-switched phase-controlled thyristor that provides a variable DC voltage output to the externally mounted DC link reactor. The reactance coil equalizes the current and preserves its continuity over the entire operating range of the system. The output of the reactance coil supplies the load switching thyristor bridge or the load bridge. The load bridge provides variable frequency AC output across the alternator stator terminals.

The control cabinet contains the UCSB controller, I / O, power distribution and power supplies. The pump cabinet contains the cooling pumps and other elements of the cooling system.

II.2.1 Power conversion cabinet:

Electricity conversion cabinets have hinged covers which must be opened by means of a tool and are fitted with a lockable padlock to lock the cover so that it remains in the closed position. The rear parts are covered with bolted panels which are only accessible for the high voltage busbar connections. Here is what is in the electrical conversion cabinets[17]:

- Power conversion module (PCM)
- Current sensor interface cards (FCSA)
- Tension reaction weighting card (NATO)
- High voltage trigger interface cards (FHVA)
- High voltage bridge interface cards (FHVB)
- Excitation trigger pulse amplifier cards (FGPA)
- Source bridge line filter
- Load bridge line filter

A) Power Conversion Module:

The PCM includes the source and / or load bridge rectifiers,

protection, current sensors and branch reactance coil assemblies. The

components vary according to the different nominal characteristics of the bridges depending on the

required output power. Three-phase current (source bridge current) intended for the PCM

comes from an external transformer connected as a star triangle with a voltage of 4160 V in

entry and

2080 V at output.

- Bridge of rectifiers:

The LS2100e contains a 12-pulse source rectifier bridge and a 6-pulse load bridge rectifier. The 14 MVA system contains three 6-pulse SCRs in the source bridges and four SCRs in the load bridges per phase. Liquid-cooled heat sinks cool the SCRs and protection circuits.

- Branch reactance coils and cell protection circuits [17] :

The switching reactance coils are located in the AC branches supplying the SCRs and the protection circuits are capacitance resistance (RC) circuits which rotate between the anode and the cathode of each SCR. The resistors of the protection circuits, mounted on long heat sinks, are located at the rear of the SCRs. The protection circuit capacitors are located below the SCRs. Cell protection circuits, line filters and line reactance coils perform the following functions to prevent malfunction of SCRs:

• Limit the rate of change of the intensity of the current passing through the SCRs and produce a current surge facilitating the start of conduction [17]

• Limit the rate of change of voltage across the cell, and when switching cells, limit the reverse voltage that can occur across the cell.

SCR protection circuits include current sharing resistors to balance the current flowing in each SCR; they also provide a means of detecting the voltage crossing the SCR to assist in the detection of failures.

The source protection circuit capacitors placed on the 14 MVA bridge are redundant. The FHVB card contains a short circuit detection circuit in either of the capacitors and sends a return signal which allows the controller to safely remove the voltage from the bridge without causing any other component failure [17]

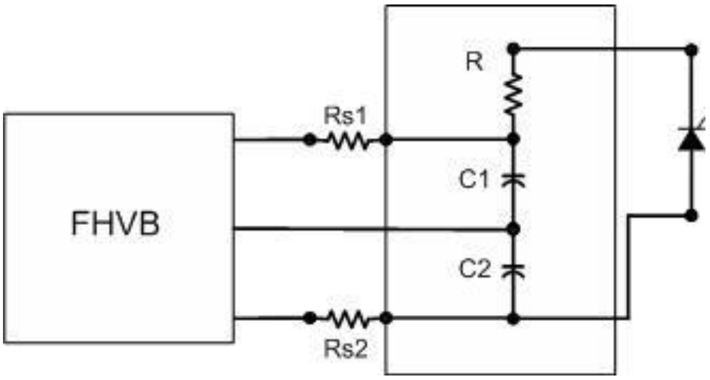


Figure II-14: Redundant system protection circuit capacitors

B) FHVA card:

The FHVA is a high voltage trigger interface card for 14 MVA bridges. It serves as a trigger interface with SCR and for monitoring cell voltage. It provides an isolated path for the trigger power supplied by the FGPA card to the SCR with interference protection. The static starter uses an FHVA for all SCRs. The FHVA includes current sensors to detect whether the SCR is conducting or blocking the voltage. It transmits this cell status data to the FGPA card and lights up its red C STATUS LED when a voltage blockage is detected [17].

- Current transformers:

Two current transformers provide source bridge output current feedback signals. The mA output signal is input to the FCSA card. The FCSA card removes excessive voltage and sends signals to the LSGI via a copper wire connected to a 12-pin plug on the LSGI. Current transformers are located on the branches

phase A and phase C of each source bridge. Phase B current is calculated by the LS2100e controller.

C) Line filters:

Each bridge has its own RC filter which protects the thyristors from sudden voltage spikes caused by switching. The line filter is protected by fuses, fitted with blown fuse indicator switches which are monitored by the controller.

II.2.2 Control cabinet:

The LS2100e control cabinet has two doors mounted on hinges accessible from the front, which are kept closed by four locked screws, which require a tool to open it and a single point handle. The handle is equipped with a lockable padlock to lock the cover so that it remains in the closed position. The following components are located inside the control cabinet [17] :

- Control supply circuit breaker
- Control power transformer and power supplies
- Standalone version B of the universal controller (UCSB)
- Relays mounted on panel
- LS2100e Static Starter I / O terminal board (LSTB) (I / O terminal of the LS2100e start control (LSTB])
- LS2100e Static Starter gating interface board (LS2100e static start trigger interface board)

- Power supply and connection electrical input supply (XOVR) • Customer connection blocks

A) UCSB controller:

The UCSB controller is the nerve center of the LS2100e control system. The UCSB controller operates as a stand-alone unit and integrates all of the control and protection functions for the LS2100e control system. The UCSB controller communicates with all the I / O via serial interfaces: Ethernet interface to UDH (unit data highway) and HSSL (high-speed serial link). The LSGI card supplies the input current of 28 VDC. All LS2100e configurations are supplied with a single UCSB controller.

B) Control power transformer:

The control power transformer supplies a 120 VAC supply secured by fuses to the control cabinet and the FGPA card. The fuses in the control cabinet protect the primary circuit and the secondary circuit of the transformer.

C) Power supplies:

The control cabinet includes three power supplies: a control power supply and two LEM power supplies. The control power supply receives 120 VAC from the control power transformer and supplies 28 VDC. 28 VDC power supplies all circuit boards, the Ethernet switch, and the optional touch screen. The LEM power supplies receive a current of 120 VAC from the control power transformer and provide a current of ± 24 VDC.

II.2.3 Converter trip control:

In any operating mode, the electronic control system synchronizes the ignition of the source converter and the load converter. It synchronizes the ignition according to the synchronous machine bus and AC line voltages using attenuated bus-ground signals as primary feedback. The LS2100e control system combines these inputs to produce analog line-to-line voltages for the two converters. It integrates the voltages in order to obtain flux signals. The passages at zero flow signals are used to synchronize the phase-locked loop (PLL) for the priming control of the two converters. At low speed, before the PLL is effective on the load side, the zero crossing marks are used as a time reference for the forced switching initiation.

II.2.4 Switching:

The source bridge always works in line switching mode. Therefore, the AC line voltage transfers conduction from one thyristor to another. The load bridge can operate in forced switching or in load switching depending on the alternator speed and flux level. When the alternator rotor (field) is in rotation, the quasi-sinusoidal field flow cuts the stator coils and produces a set of three sinusoidal voltages in the stator. The sinusoidal voltages are offset from each other by an angle of 120 ° (electrical). The magnitude of this counter-electromotive force (FCEM) is proportional to the speed and the field strength. At low speeds, the induced

FCEM is not sufficient to switch the thyristors in the charge converter. In this mode, the load converter must operate in forced switching [13].

A) Forced switching operation:

The forced switching operation is used when starting the turbo alternator from the speed of the tacker and continues until the counter-electromotive force of the machine is sufficient to achieve automatic switching. In forced switching, the conduction of the charge converter is stopped by passing the source converter to the inversion limit until the current of the DC link inductor is equal to zero. Thus, the DC link current is divided into large segments of 60 ° from the electrical angle of the machine.

The high inertia of the turbine alternator prevents rapid acceleration. To minimize the effect of harmonic heating at the slot-to-slot corner interface of the rotor, the starting current is also limited. It is necessary to start the turbine alternator from a low speed (mechanical) tacker. The control system can recognize the machine flow at the frequencies corresponding to tacking speeds of 6 rpm, since the decrease in the machine's RI (current, resistance) is negligible at the operating current of the LS2100e control system .

When a start is triggered, the static starter controls a sufficient field voltage to produce an unloaded excitation voltage (AFNL) on the alternator rotor. The command waits for the field current to increase for approximately three frame duration constants (12 sec). During this time, the LS2100e command follows the position of the machine rotor by observing the voltages induced in the stator at the rotational frequency of the tacker.

At the end of the excitation establishment delay, the static starter applies a fixed level of current to the coils of the corresponding stator in order to produce a positive torque. Normally, the LS2100e command is blocked on the flow and the transitions of the stator of the machine in segment ignition mode of the operation by forced switching.

In segment ignition mode, the ignition of the load bridge is synchronized to the machine flow connections, and the machine is actuated by being close to the power factor (FP) of the unit to obtain the maximum torque per amp of the stator current. The cruise control becomes active in segment ignition mode. At approximately 2.5 Hz, the PLL is engaged, which ends the segment ignition mode. Forced switching operation continues until the synchronous machine reaches a frequency for which it has sufficient CEMF to switch the load bridge. The LS2100e command activates the transition to forced switching operation.

B. Automatic switching operation:

During automatic switching operation, the machine must operate at a determining FP to guarantee switching of the load bridge. The electronic control acts to keep the machine's FP (and the torque per amp) as high as possible. This can be achieved by initiating the load bridge as late as possible while maintaining sufficient headroom for successful current switching from one cell to the next.

For a given load current and inductance of a machine, successful switching requires a corresponding amount of volts-seconds. The control reads the peak volts-seconds of the machine's integrated phase-phase voltage and current.

The switching inductance of the machine is a constant stored in the memory of the microprocessor system. The amount of switching volts-seconds required is calculated by the microprocessor, based on current and inductance. Using this volt-second value and the peak volt-second value from the previous flux wave, the last possible period for priming is calculated to give a specified margin at the end of the switching.

The switching notch identified in phase-phase voltage A-C is equivalent in amplitude to the simultaneous switching jerk on voltage B-C. The corresponding notch in voltage A-B (A and B are the two lines switching together at that time) is twice this amplitude; the notch area corresponds to twice the switching inductance per phase duration. The voltage at the switching point, where the thyristor tabs temporarily connect to the lines, is close to zero when switching; phase-phase voltage is only the direct voltage drop of the legs of the conductive thyristor.

II.2.5 Current limit control:

Due to the high inertia of the turbo alternator, the software operates within a current limit as soon as the static starter is accelerating. At low speed, the current is limited to a relatively low value in order to minimize the harmonic current induced in the rotor of the machine. As the speed increases, the current limit is recalibrated according to a configurable profile. When the turbine speed reaches a point at which it can operate independently, the current limit is gradually reduced to zero, as the speed increases. This prevents a load being exerted on the turbine when the LS2100e control is de-energized [13].

II.2.6 Cruise control:

The speed reference from the turbine controller is compared to a speed feedback derived from the voltage of the integrated generator to develop an incorrect speed input to the speed controller. The speed controller output is a torque command.

The torque command signal applies to the control of the source and load bridge. The torque of the machine depends on the flux, the tension and the angle between them.

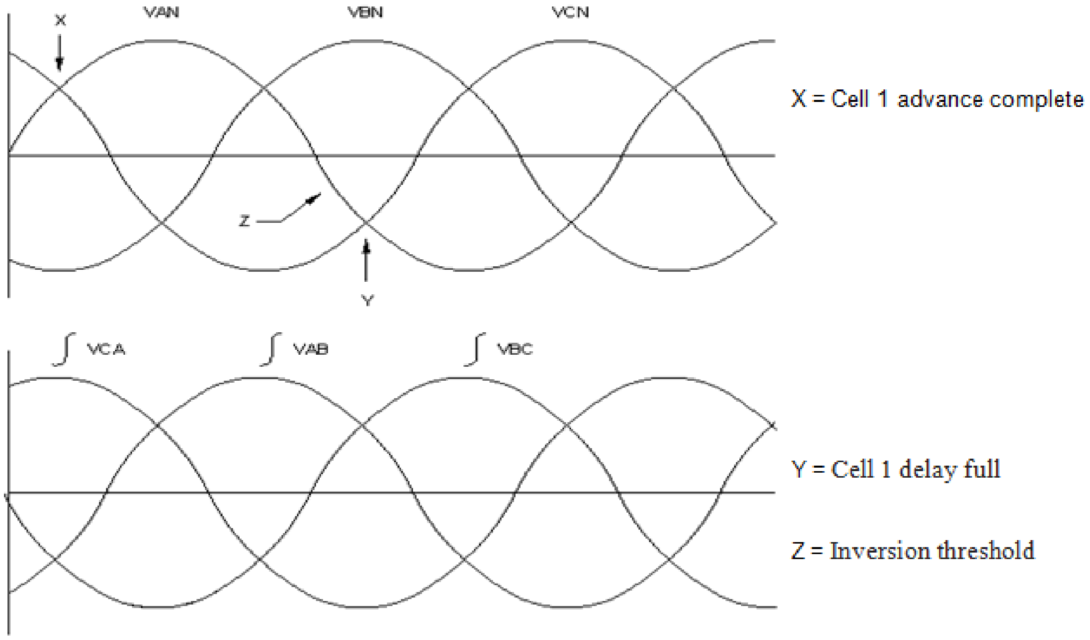
Adjusting the magnitude of the stator current at a fixed angle or maintaining a constant current and varying the displacement angle therefore makes it possible to control the torque. The source bridge controls the current, while the load bridge controls the angle. At one point, the couple is only controlled by one of these means. Torque control to the source bridge applies to a maximum and minimum current limiter. The minimum current level, generally 20% of the nominal current, is defined so as to maintain the direct current in the DC link [13].

The minimum current limit also affects the ignition ignition angle (and the FP of the machine), as soon as the torque command produced by the speed controller is less than the minimum current limit. In this case, the charge ignition angle (and the FP of the machine) varies according to the torque control, while the stator current remains constant. The torque is controlled via the machine's FP setting as soon as the torque command is below the minimum current limit. As soon as the torque command is greater than the minimum current limit, the charge ignition angle is at its righting or reversing threshold. During a start-up, the load angle is at its inversion limit. During regeneration (braking), the load angle is at its righting threshold.

During start-up, the charge control adjusts the ignition delay angle so that it is as late as possible, in order to maintain a safety margin for fixed switching (around 20 °). This control adapts to changes in stator current and voltage to maintain a constant margin angle and maximize FP.

II.2.7 Phase locked loop:

The PLL uses the zero crossings of the reconstructed 3-phase flow waves as a time reference. At each flow wave passage, it is possible to determine the angular position in the current phase A cycle on neutral of the bus voltage that. This position or phase is compared to the value in a PLL counter to derive a phase error. The error applies to the PLL regulator, which increases or decreases the clock frequency. This in turn causes the PLL counter to return the error to zero. The PLL counter divides an electrical cycle from A-N into 1024 increments, then resets at the end of each cycle. The control software can read the value of the PLL counter at any time. The priming delay of a particular thyristor can then be calculated using the value read on the PLL counter, the desired priming angle and the appropriate offset for the cell being primed.



X = Cell 1 advance complete

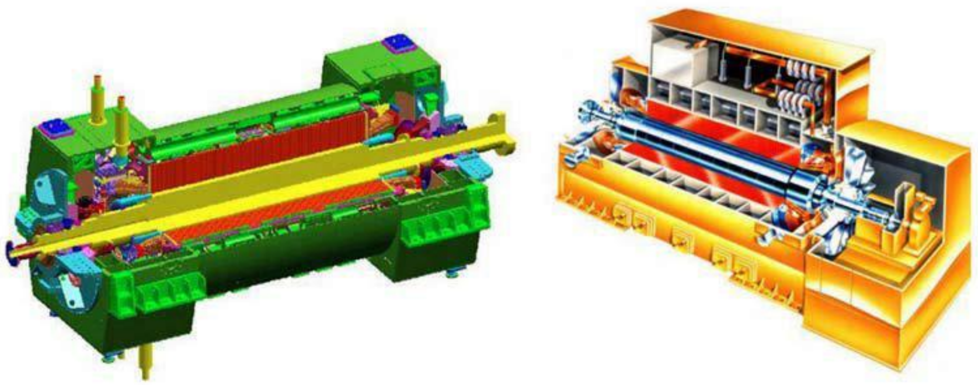
Y = Cell 1 delay full

Z = Inversion threshold

Figure II-15: Zero crossings of flow waves

II.3 Alternator:

The hydrogen-cooled Type 324LU turbo-generator is fully closed to operate using hydrogen gas as the cooling medium. The ventilation system is a self-contained unit comprising gaseous refrigerants and fans. The separate excited rotary field, powered by the turbine, rotates inside the stationary armature and is supported by bearings located in the flanges mounted on the alternator frame.



Stand-up configuration Base mounted configuration

Figure II-20: Hydrogen-cooled turbo-alternator

The device is designed to operate continuously, supplying power to the armature terminals, with devices to maintain the pressure and purity of the hydrogen and provide a supply of cooling water and lubricating oil. Temperature sensors and other devices are installed in the machine and connected to it to measure winding and hydrogen temperatures, as well as the pressure and purity of hydrogen. The alternator is designed to withstand all normal operating conditions without harm. The stator housing is designed to limit the destructive effects of an internal hydrogen explosion [5].

II.3.1 Stator frame and spring mounting:

The stator frame consists of a gas tight cylindrical housing made of welded plates, internally reinforced by fixed plates and axially by guide bars and spacers.

The perforations in the stator core are permanently pressurized in the axial direction of the alternator. The stator core is also installed on a spring base to isolate the radial and tangential vibrations of the core from the external chassis. The movements of the nucleus being limited to safe amplitudes, the vibrations of the chassis are less and the operation is quieter.

The stator frame is held on its foundation by one of two methods - leveling devices("Fixator") or plates and shims. The leveling devices serve both to uniformly support the alternator and to ensure adjustment of the vertical alignment. The heavy flanges that contain the alternator bearings are bolted to the ends of the chassis. The chassis also acts as a support and enclosure for gas refrigerants. All flanges, coolers, access hatches, etc. must be carefully sealed to prevent hydrogen leakage from the alternator. Lifting bolts bolted to the sides of the chassis are provided to attach lifting slings when installing the alternator.

II.3.2 Stator core:

The stator core is made up of isolated segmented perforations (Figure II-12), made of high quality silicon steel. These perforations are assembled in an interposed fashion on dovetail keys integrated into the timing bars and are separated in groups using spacer blocks to form ventilation ducts. The perforations are punched in thin steel sheets and contain open-end notches for the armature bars with dovetail keys to hold the armature bars in place as shown in Figure II-12 [5] [14].

The assembled perforations are clamped in a rigid cylindrical core by the pressure applied by the nuts tightened in the threaded ends of the armature bars by means of flanges made of ductile iron. Pressure is applied to the teeth through non-magnetic steel needles located under the flanges. To reduce the heating of the extremities caused by the flow of leakage from the extremities and the resulting electrical losses, the last groups of perforations are brought to the end of the stator core in order to increase the space between the perforations and the rotor. . The perforations are insulated by a thermosetting varnish which retains its insulating capacity at temperatures exceedin the normal operating range of the alternator [14].

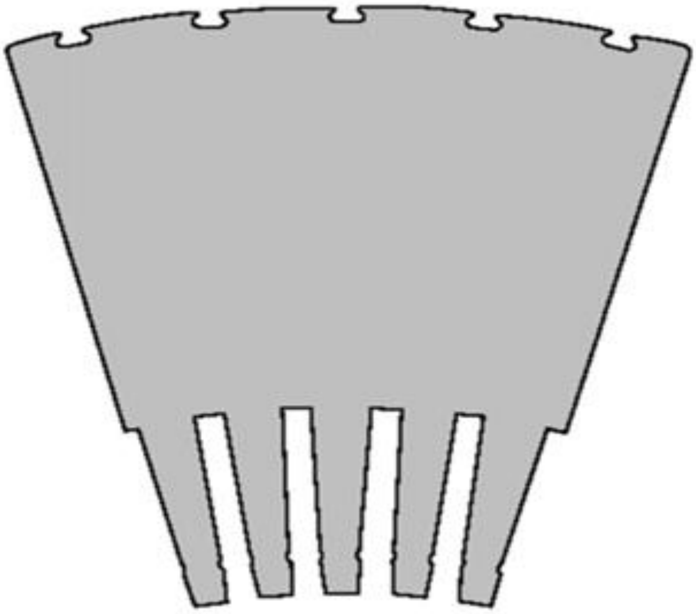


Figure II-21: stator perforations

II.3.3 Winding of the stator:

The stator winding (Figure II-17) is made up of insulated bars assembled in the notches of the stator, at the joined ends to form coils and connected to the appropriate phase windings using the connector rings. Each phase is divided into groups of coils separated by 180 °.

Figure II-22: Typical terminal turns of the stator winding and connections for a hydrogen-cooled bipolar alternator

The phases are electrically separated by 120 °. The stator bars are composed of insulated copper conductors (strands) transposed using the "Roebel" method so that each strand occupies in the notch each radial position of the bar for an equal length along it. This arrangement avoids the loss of current in circulation, which would otherwise be present under load due to the self-inductive distribution of the magnetic flux in the notch of the coil. The armature bars are held in the notches of the core by Textolite shims embedded in the dovetail notches as shown in (Figure I I-14) [5] [15].

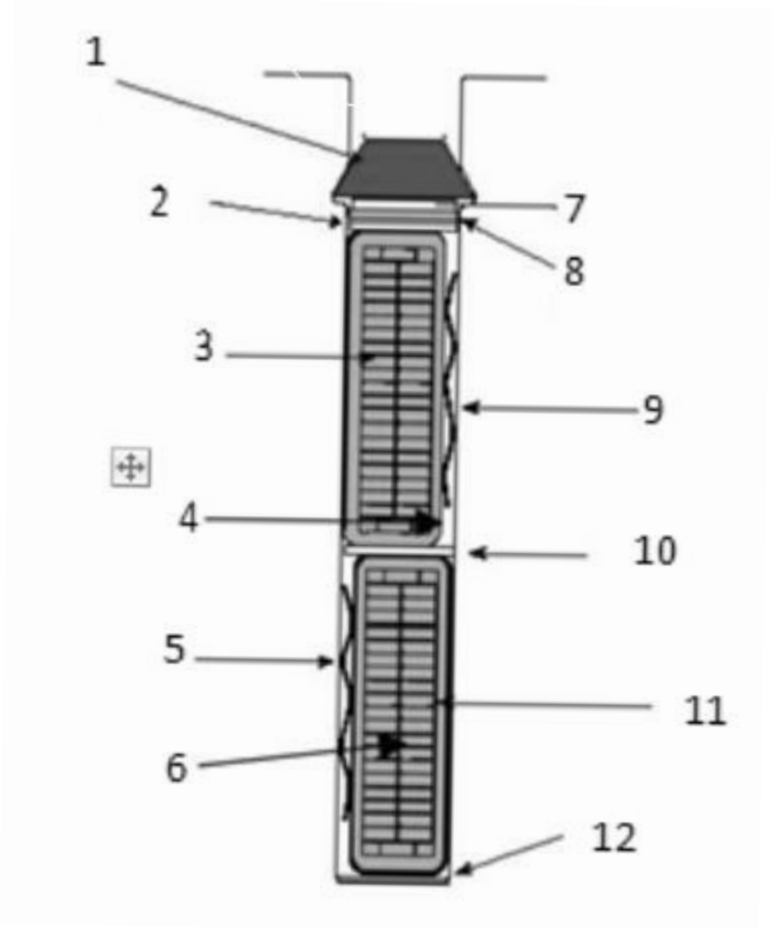


Figure II-23: Armature conductors assembled in "Roebel" bars

1: Stacking block

2: Top fillers

3: Upper bar

4: Graduated tape on layers of mica tape

5: Side wave spring

6: Vertical separator

7: Slide

8: Upper wave spring

9: Side wave spring

10: Resistance temperature sensor or filling material

11: Lower bar

12: Lower bar filling material

II.3.4 Alternator rotor:

The field coils are located in the longitudinal notches machined radially inside the body. The field coils are held in the notches by steel shims against centrifugal force. These shims are inserted in the dovetail openings machined in the notches of the rotor. The shims and the coils which they hold in place have aligned radial holes forming numerous radial passages which connect the rotor sub-notch and the air gap. The gas flows axially under the end windings of the rotor and into the sub-notches, then radially outwards through the radial passages and finally discharges into the air gap. The radial gas flow removes the heat produced in the coils. The gas flowing along the air gap above the rotor surface cools the rotor externally.

The rotor fans, used for alternator ventilation, are mounted near the ends of the rotor.

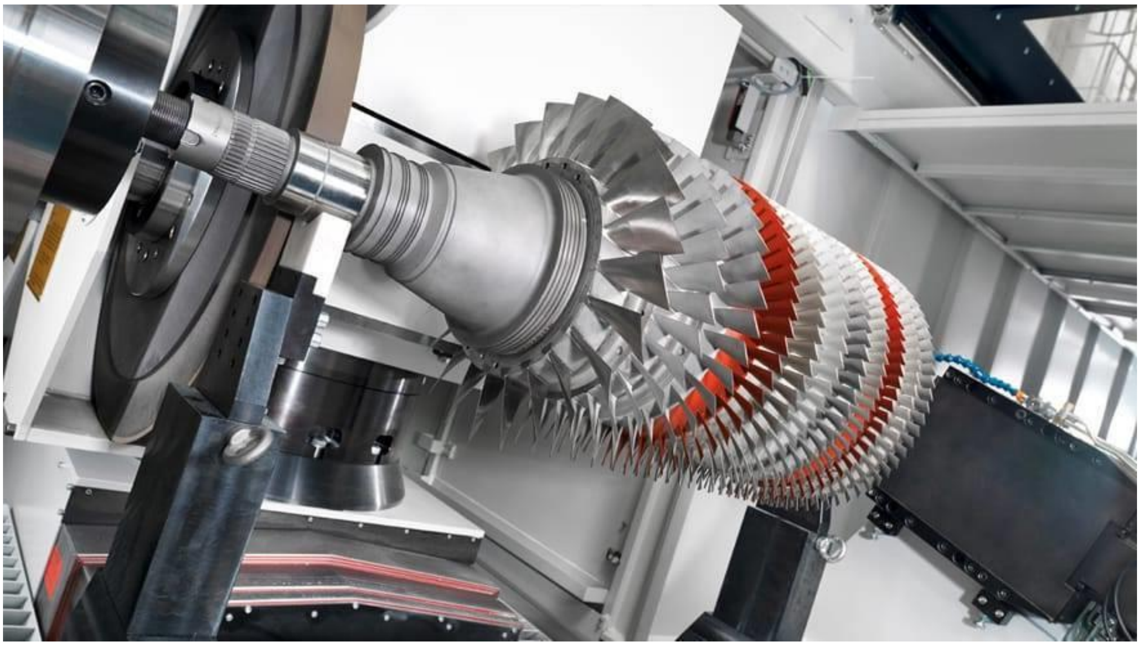


Figure II-24: Assembled rotor

II.3.5 Winding of the field and retaining rings:

The field winding consists of copper bars, machined inside the coils. Several turns in a pair of notches surrounding a pole form a coil. Several coils are assembled around each pole to form the winding. The individual turns are isolated from each other. The coils are isolated from the notch wall in the body by molded notch channels. In order to provide the maximum level of ventilation and cooling, the ends of the field coils remain bare. An insulation by molded ring is located between the coils and the retaining rings, a blocking by epoxy glass installed on the end windings separates and supports the coils and reduces their movements under the constraints related to thermal variations and rotational forces.

The final turns are held in place against centrifugal force by heavy retaining rings machined from high strength alloy steel forgings, heat treated, shrunk and tightened on the rotor body.

II.3.6 Collector and collector connections:

The field windings are supplied with current via the collector rings, electrically connected to the field winding by means of insulated copper bars assembled at the drilled center of the rotor forging. On one end of the terminal studs of the connection bars, which are assembled in radial holes in the rotor shaft, the winding connects to the bars. At the end of the shaft, this connection is made using collector studs. The manifold side connections use an elastomeric seal system to contain the pressure of H2.

A detailed description of the collector is provided in separate instructions listed in the table of contents of the assembly’s combined manual.

II.3.7 Brushes and adjustment of the brush holder:

A detailed description of the brushes and holder for the brush holder is provided in separate instructions listed in the table of contents of the assembly's combined manual.

II.3.8 Flanges and bearings:

The alternator rotor bearings, the shaft seals (for hydrogen) and the oil passages for the oil supply of these parts are contained in the outer flanges. The flanges are separated on the horizontal center line for easier removal. The joints between the flange halves and those between the flanges and the stator frame are made with sealing grooves for the insertion of the sealant in order to seal the gas inside the machine.

The rotor bearings are supplied with ball seats to allow proper alignment of the bearings with the rotor trunnion surfaces. A detailed description of the bearings is provided in separate instructions listed in the table of contents of the combined package manual. A shaft seal attached to each outer flange inside the bearing prevents hydrogen leaks from the alternator along the shaft. This assembly allows the inspection of the alternator bearings without emptying the gas into the machine. A detailed description of the shaft sealing system is provided in separate instructions listed in the table of contents of the combined assembly manual. The bearing and shaft seal compartment on the manifold side of the unit are both isolated from the alternator chassis to avoid flow or induced currents in the shaft.

The inner flanges or gas shields are located between the ends of the armature windings and the outer flanges to separate the discharge gas from the fans from the gas entering the fans.

II.4 Applications:

During start-up, the turbine control transmits to the LS2100e control the execution command and the speed setpoint signals. The static starter activates the power converter in closed loop mode to supply the variable frequency amperage to the alternator stator. By controlling the excitation voltage of the alternator and the intensity of the stator, the static starter can adjust the torque produced by the alternator and control the acceleration and speed of the turbine-alternator assembly.

During start-up, the excitation voltage set point is provided by the LS2100e command in order to regulate the voltage across the alternator stator.

II.4.1 Gas turbine start sequence:

Initially, the alternator-gas turbine assembly rotates at a tacking speed of 3-6 (rpm). At start-up, the LS2100e command connects to the alternator stator and takes control of the excitation voltage reference. The LS2100e command then accelerates the turbine to reach the purge speed set point (generally 25% of the synchronous speed). The turbine maintains the purge speed for approximately six minutes [13].

After purging, the LS2100e control input is switched off and the turbine can slow down until reaching the ignition speed of 15%. The input is turned on again and the turbine starts. The turbine briefly keeps a constant speed, to allow a heating time.

After the heating period, the static starter accelerates the turbine until reaching autonomous speed 90% of the synchronous speed. The LS2100e control is switched off and disconnected from the alternator.

II.4.1 :Gas Turbine Startup Sequence:

Initially, the gas turbine-generator set is spinning at turning gear speed, typically 3 to 6 rpm. At startup, the Static Starter connects to the gene000000000000000000000000rator stator and assumes control of the exciter field voltage reference. The Static Starter then accelerates the turbine to the purge speed setpoint (typically 25% of synchronous speed). The turbine is held at purge speed for approximately six minutes. Following the purge, the Static Starter output is turned off and the turbine is allowed to coast down to the firing speed of 15%. Once at firing speed, the output is turned on again and the turbine is fired. The turbine is briefly held at constant speed to allow for warming. Once the warming period is completed the Static Starter accelerates the turbine to its self-sustaining speed, at which point the is turned off and disconnected from the generator[17] .

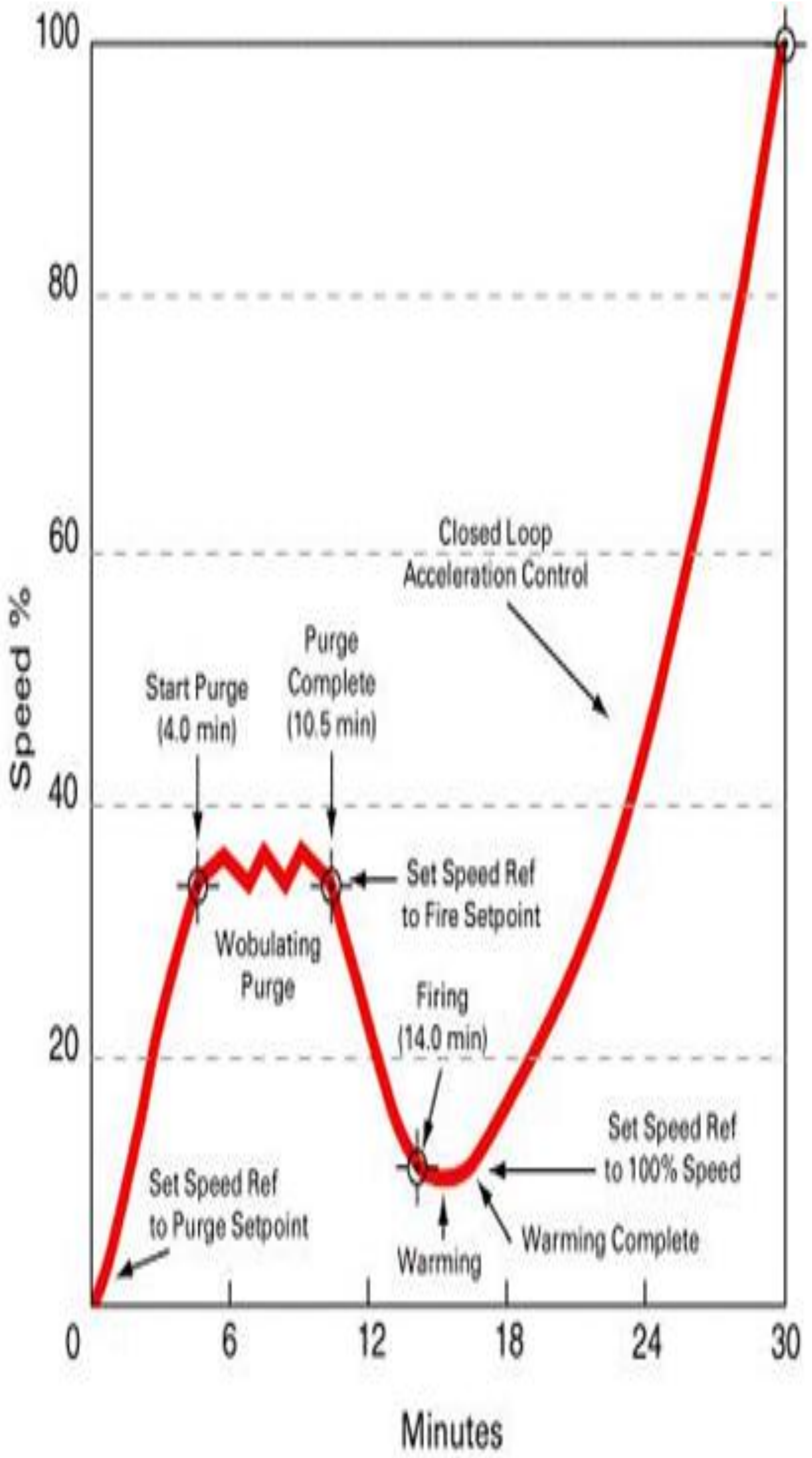


Figure II-25: Gas turbine start-up sequence

II.4.2 Torque vs. Speed Curves:

A typical gas turbine torque-speed curve shown below, shows the turbine load torque (unfired torque and fired torque) and the generator output torque (motor torque). The acceleration torque is determined by the difference between the generator output torque and the turbine load torque. The acceleration torque and the inertia of the shaft determine the acceleration rate. As the accelerating torque becomes larger the turbine is accelerated faster. The Static Starter adjusts the generator output torque to have the turbine follow the startup sequence[17]

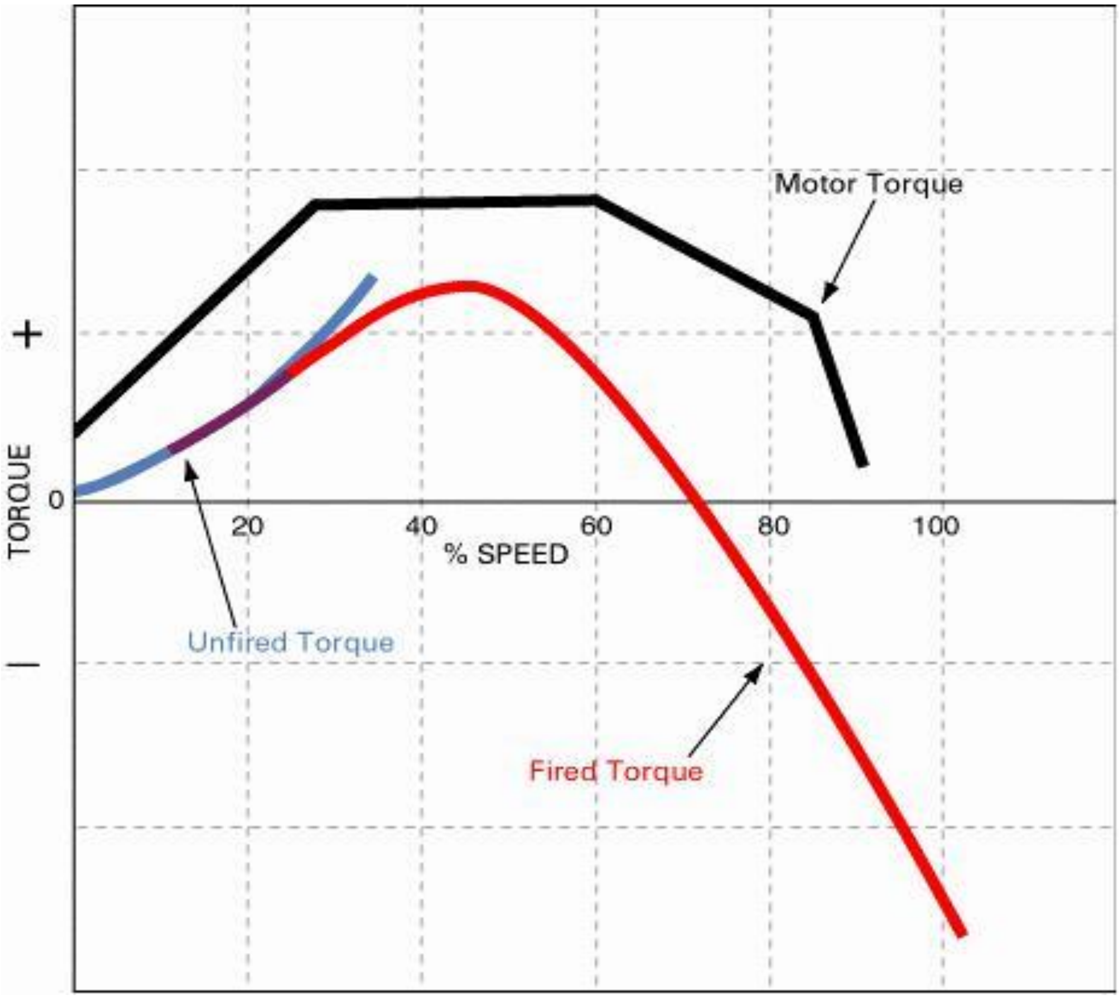


Figure II-26: Velocity and torque curves

The turbine accelerates to approximately 25% of the speed in non-lit mode and 15% of the speed in lit mode. The period between these two points represents the wobulation purge and the deceleration. At 90% of the speed, the torque produced by the turbine is sufficient to accelerate until reaching maximum speed and the static starter is deactivated[17] .

II.4.3 :Generator Voltage vs. Speed Curve:

The following figure shows a typical generator starting voltage profile. During startup the generator field current is controlled so that the generator stator flux does not exceed allowable limits. The Static Starter output voltage increases linearly from 0 to its rated value of 4160 Vac as the speed increases from near 0 to 18 Hz (for 7F turbine applications), providing constant volts/hertz (flux) on the generator. Above 18 Hz, the Static Starter output voltage is held constant and volts/hertz falls off inversely with speed [17] .

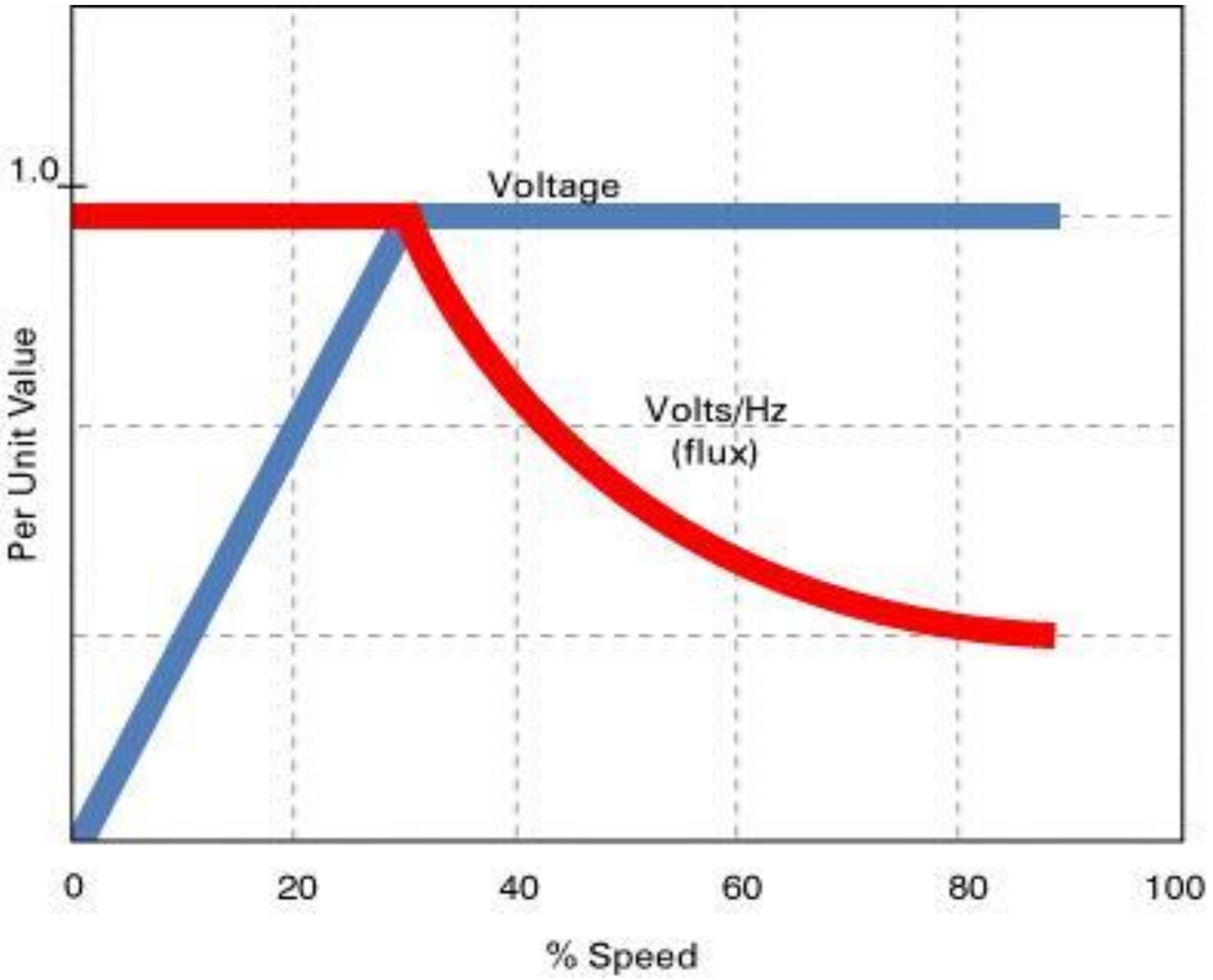


Figure II-27: Alternator flux / voltage with respect to speed curves

Conclusion:

In this chapter an overview of the LS2100e static starter and the various control elements as well as its operating principle. We have also described the operating principle of the Type 324LU turbo-alternator.

The different gas turbine start-up sequence, speed and torque and flow / voltage of the alternator were presented in this part.

Chapiter-3

Introduction :

The Load Commutated Inverter (LCI) fed synchronous motor has gained wide acceptance as a high power variable speed drive due to its excellent efficiency and reliability characteristics. The standard LCI drive configuration comprises a fully controlled six pulse thyristor bridge rectifier (using conventional SCRs) which is connected to a similar fully controlled thyristor inverter by a DC link inductance

III.1.1 :Load-Commutated-Inverter (LCI) Supplied Synchronous Motor Drives

Steady-state operation of a load commutated inverter (LCI) fed synchronous motor drive is analysed by means of a digital computer based solution of the synchronous machine equations. The solution permits calculation of current, voltage, and torque waveforms and includes the effects of finite DC link inductance, saliency of the rotor and all machine resistances. The continuity constraints for steady-state operation are exploited to enable the proper initial conditions to be calculated directly, without the need for iteration. Operating points are described by the firing angle gamma /sub 0/, and the overlap angle mu , and are computed for an assumed DC supply voltage of 1.0 per unit. The linearity of the state equations allows the normalised solutions to be scaled to any desired value of torque, DC link etc. [19]

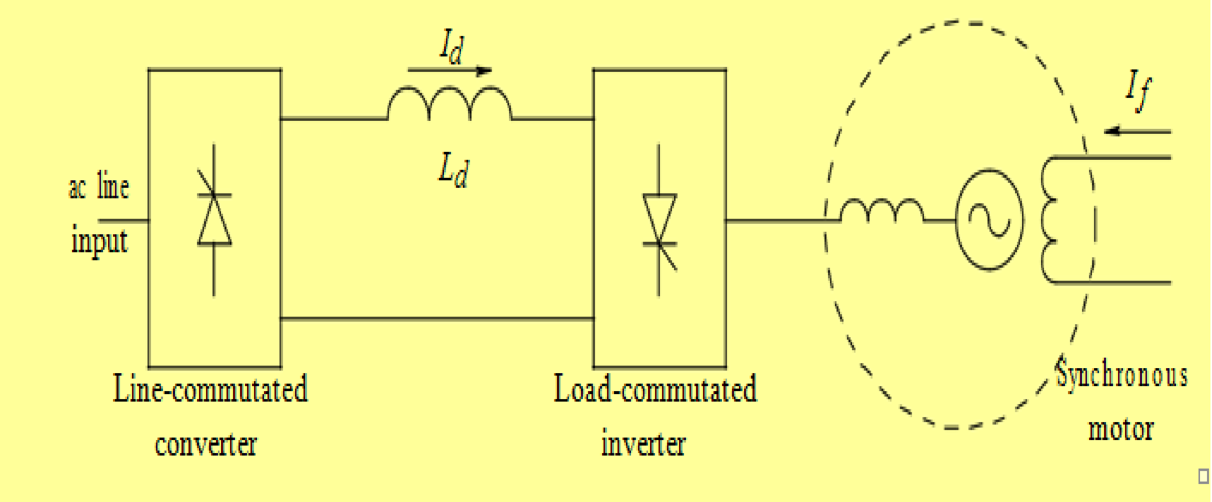


Figure III-1 : LCI Supplied Synchronous Motor Drives

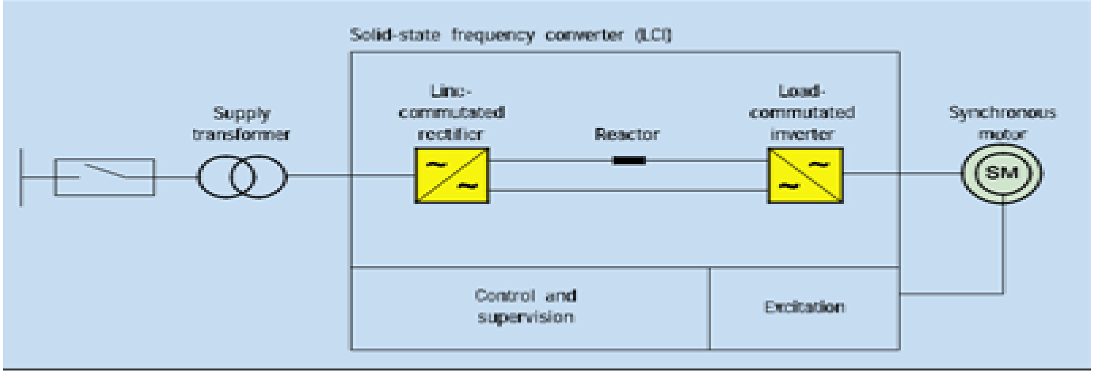


Figure III-2 :LCI supplied Synchronouns Motor(DC-AC Reactor)

Load Commutated Inverter Fed Synchronous Motor Drive is shown in Figure III-3. The inverter is a current source inverter employing thyristors T1 – T6. The commutation of inverter thyristor is done by the voltages induced in armature of the synchronous motor. A chopper is used to obtain a variable dc voltage Vds from the fixed source voltage V. The Vds is varied with Vdl so that a required current is supplied to the dc link, and therefore, to the motor. [23]

During motoring, the power flows from the dc mains through the chopper, dc link and inverter to the motor. When the inverter firing angle is changed from close to 180° to 0°, the voltage Vdl reverses. If chopper operation is also changed to make Vds negative but less than Vdl in magnitude, the power flows from the load, through the machine, inverter and chopper to the dc mains, giving regenerative braking operation. Here arrangement for dynamic braking is not shown, but it can be incorporated in the same way as shown already. [23]

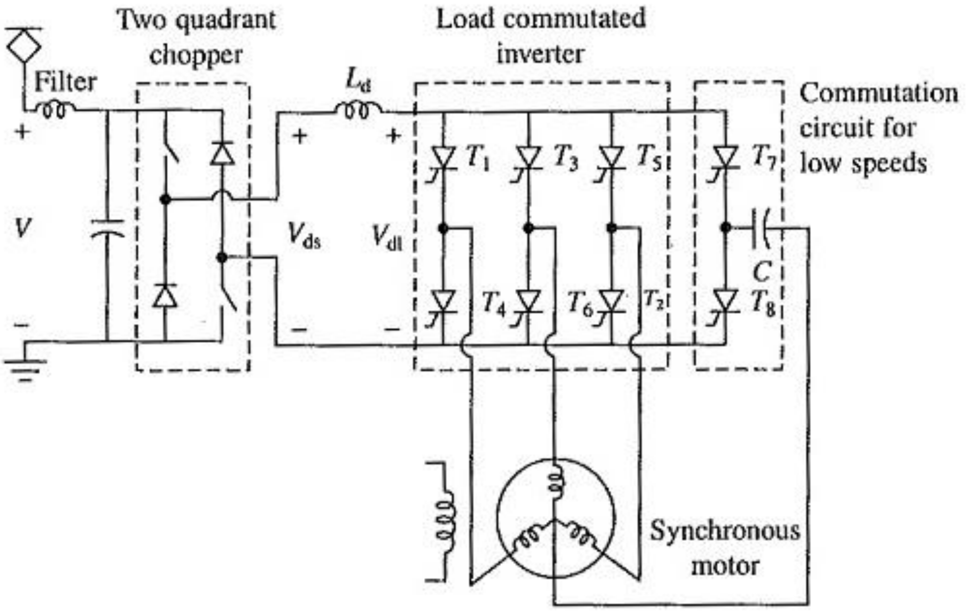


Figure III-3 :motor Drive By LCI

Armature induced voltages are too small to commutate inverter thyristors at low speeds, including standstill. Thyristors T7 and T8 and capacitor C are used to commutate inverter thyristors at low speeds. Around 10% of the base speed gate pulses are withdrawn from T7 and T8, and the load commutation is employed. [23]

III.1.2 :Advantages of LCI supplied Synchronouns Motor Drives :

-High power levels

-Field windings on rotor carrying a dc current

-Thyristor PPU needed at these power levels

-DC-link between utility and inverter is a nearly constant current (Id) rather than a constant voltage (Vd) as in previous circuits-Inverter thyristors commutated by load (synchronous motor).

III.2.1 :Synchronous Generator :

A synchronous generator produces alternating current in the armature winding (usually a three-phase winding on the stator) with dc excitation supplied to the field winding (usually on the rotor). [20]

The generation of electrical power is mostly done by a synchronous generator. This machine is robust, simple to control and almost maintenance free in a brushless (rotating rectifier) version. It generates electrical power with a frequency proportional to the speed of the rotor, so the electrical frequency and mechanical speed are synchronous, which explains the machine's name. [21]

III.2.2 Working principles :

The machine generates electrical power in the stator coils by a rotating magnetical field which is generally produced by a DC magnet. The DC power for this magnet can be supplied externally, but it is convenient to integrate a small generator, the exciter, on the same shaft within the same housing. In any case to feed this magnet, the DC current has to be supplied to the rotor. A simple way is through two slip-rings, but this involves wear and regular maintenance. A more sophisticated, but maintenance free solution is to integrate a small AC generator (exciter) on the rotor, rectify the current and supply it to the rotor coil, all on the same shaft, avoiding any slipping contacts (therefore rotating rectifier). The excitation current for the exciter is provided by a DC current to the exciter stator which is generated by the output power of the main generator. [21]

This method allows to design a clever system, integrating even a simple but efficient voltage control. Since the voltage of the main generator drops with an increasing load, its excitation has to be increased to compensate. This requires more current from the exciter, which is achieved by increasing its excitation. So the DC supply for the exciter stator can be used to control the main generator's voltage. Such a control is done electronically by an automatic voltage regulator (AVR). A certain output voltage is preset and the control adjusts the excitation to keep the output voltage under all loads close to the preset value. Today's brushless, synchronous generators include an AVR. [21]

The machine is able to self-start by its residual magnetism: as soon as the machine rotates, a small output voltage is generated starting to feed a small current through the AVR to the exciter, which in turn increases the output voltage. This control loop develops the nominal output voltage within a few machine sums. It is possible that the residual magnetism was lost. In this case it has to be rebuilt. The same method as for asynchronous machines can be used and is described in the next chapter. [21]

The frequency, however, has to be regulated, as an increased load will decrease the rotor speed. Such a speed control could be most simply done by hand or automatically by an automatic governor.

At least two important design/selection considerations for generators related to the control of MHP sets shall be pointed out here:

- the generator must be equipped with special bindings able to withstand the runaway speed of the turbine (in case of crossflow-turbines approx. 1.8 times the rated speed).

- if possible use standard generators. BYS Nepal for instance uses wherever possible 4- pole, brushless-type generators, equipped with an electronic automatic voltage regulator (AVR). These provide fairly constant voltage over a wide speed range which is important for manual or simple governor-based flow controls. Moreover they require virtually no maintenance. [21]

III.2.3 : Advantages of Synchronouns Generator

-Generally larger sizes

-Directly connected to utility without PPU

-Three-phase winding on stator - DC field winding on rotor

-Angle between rotor flux and stator flux not necessarily 90o

-allowing generator to sink or source VARS. [22]

III.3.1 : Per-Phase Model and Power-Angle Characteristics

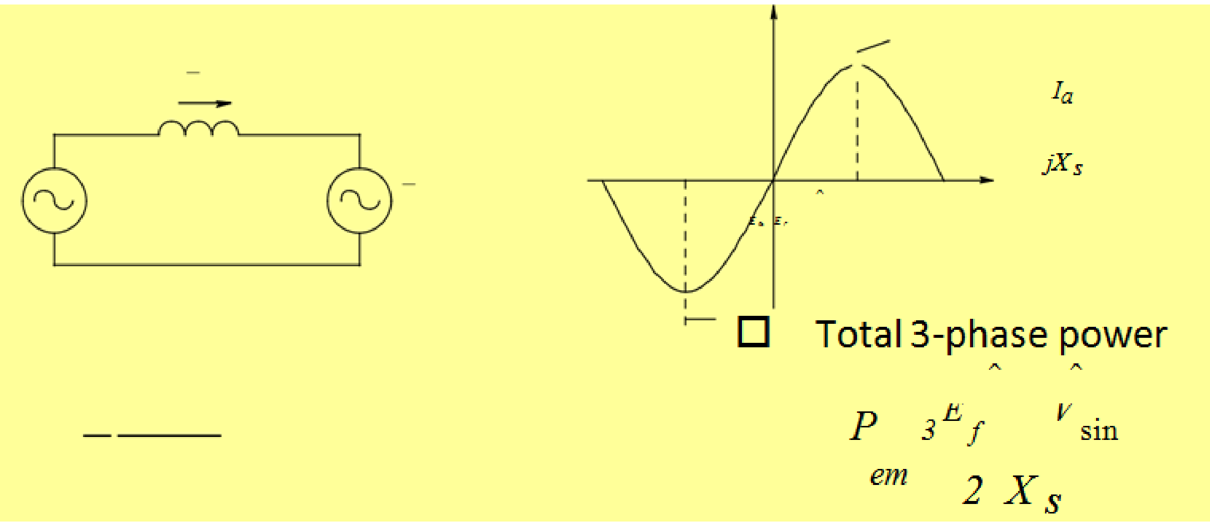


Figure III-4 : Model and Power-Angle

For angles between

(90 o and +90 o rotor) speed remains locked to line frequency

When the machine is asked to either supply or absorb to much power□the angle will move outside the 90o range. In this situation the rotor will no longer be synchronized to the line and will either speed up out of control or slow down. In either case excessive currents should trip the circuit breakers. [22]

III.4.1 : Adjusting Reactive Power and Power Factor

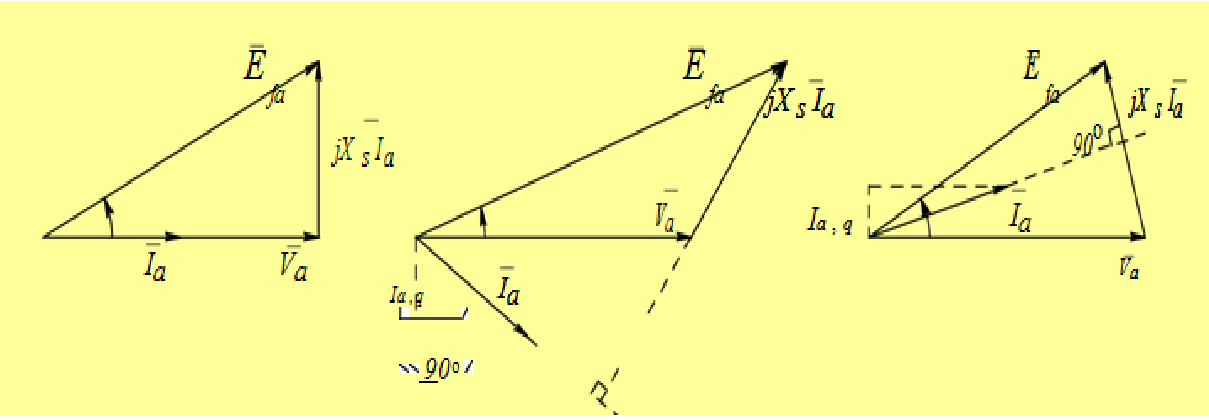


Figure III-5 : Adjusting Reactive Power and Power Factor

Unity Power Factor Operation

For every operating condition there is one value of field current that will cause the generator to deliver only real power.

Over-excitation

Increasing field current causes generator to supply more reactive power.

Under-excitation

When field current is decreased below the value for Unity Power Factor

operation, the generator will absorb reactive power. [22]

Conclusion :

A current source inverter for a load commutated induction motor drive is controlled in relation to the direct and quadrature components of the current vector as assigned in response to stator voltage, speed reference and actual speed. Control is on the inverter and the converter in relation to both components.

General conclusion :

In this work we have studied and simulated the robust control law for the control of the synchronous machine with a wound rotor (alternator) in speed in order to start the latter gradually from standstill to a speed close to the speed of synchronism.

The work presented in this thesis was devoted to the study of the modeling of the high power alternator installed in the Biskra-Oumach power station associated with a static converter (rectifier-inverter).

We then became interested in the implementation of the vector control strategy which allows to obtain a decoupled dynamic model equivalent to that of a DC machine. This allows direct control of the speed and torque via the live and quadrature components of the stator current and subsequently obtain high-performance regulation performance allowing a robust and rapid progressive start.

The results were in this interesting work to know a rejection of the disturbances and a decoupling between the couple and the flow is perfect. The adjustment by estimating the position and the stator flow of the synchronous machine allowed us to reach speed dynamics extremely confused with the command setpoint.

The results obtained by simulation show that this technique provides good static and dynamic performance during the alternator start-up, whether in regulation or setpoint tracking and that it is not very sensitive to modeling errors. Several advantages are recognized: reasoning close to the natural reasoning of the operator, the exemption from modeling, the control of systems

to regulate, the frequent obtaining of better dynamic performances and its intrinsic qualities of robustness By contributing to conventional regulators and state regulators.

The Load Commutated Inverter (LCI) fed synchronous motor has gained wide acceptance as a high power variable speed drive due to its excellent efficiency and reliability characteristics. The standard LCI drive configuration comprises a fully controlled six pulse thyristor bridge rectifier (using conventional SCRs) which is connected to a similar fully controlled thyristor inverter by a DC link inductance. The inverter is attached to a wound rotor synchronous machine. In this Thesis a new, algebraically simple, steady-state, linear model of an LCI fed synchronous motor drive with a finite DC link inductance is presented. The behaviour of the DC link inductance is included in the machine equations in an implicit fashion, thereby avoiding the difficulties involved in direct incorporation. This is facilitated by deriving a simple equivalent circuit, representative of the DC link and inverter, at voltage ports which connect the power electronic network and the machine. The power electronic analysis is based on a simple backward Euler integration algorithm and considers the inverter SCRs to be two state variable resistors. The machine is modelled by Park's equations. Initial currents for a steady state operating point are found by iteration; direct calculation being found to be insufficiently accurate. The first iteration to the initial conditions and the source voltage / field voltage ratio are calculated by a state space method which assumes infinite DC link inductance. A practical simulation time step is selected by simulating an ideal current source in the DC link. A constant mechanical firing-angle LCI drive system (using a 3 kVA microalternator) was constructed in order to experimentally verify the new modelling strategy. The drive featured a filtered DC source voltage and a forced commutated start up strategy. An excellent level of agreement between the theoretical and measured results was achieved when the machine was operated in its linear region. Significant discrepancies did not arise until the machine was heavily saturated. A comparison between the new LCI drive model, a state space model which assumes infinite DC link inductance, and a third model which considers the machine to be a voltage behind a subtransient reactance was performed for an LCI drive with constant inverter margin angle control. Both cylindrical and salient pole machine configurations were examined. There was a good level of agreement between the two time domain models except in the predicted levels of torque ripple. Other differences only became apparent when the DC link inductance was very small. The "voltage behind the subtransient reactance" method was only slightly less accurate than the infinite DC link inductance method except where the machine subtransient reactances were relatively large. Significant differences between the three models were noted, however, when a machine without damper windings was studied, due to the increased impact of DC link current ripple. The versatility of the new technique was demonstrated by the inclusion of source voltage ripple for some operating points. The new modelling strategy was also applied to other drive system configurations - an induction motor supplied by an inverter with 120° conduction and a similar inverter fed Permanent Magnet (PM) motor drive - and a sample operating point was calculated for each system. The initial condition iteration process was not convergent for the induction motor drive; thus the new model is better suited to machines with standing back emf components. A simple predictor-corrector algorithm was used to predict a sample step response for the above PM motor drive and it is hoped that this method may have application in dynamic analyses of LCI drives.

Bibliographical references:

[1] Power-technology site « projects : Biskra-combined-cycle-power-plant »

[2] Société Algérien De Production De L'électricité, « document technique: CONVENTION PIECE I », 2013.

[3] Power Plant Training Center, "Technical Document Overview of the gas turbine power plant "Alstom Ltd, 2003.

[4] GAMA POWER, "technical document: PLAN DE MASS" KDM / SPE 2013 & GE Energy, "Technical Paper: Hydrogen Cooled Alternators" General Electric Company, 2009.

[5] G E Company, "Technical document: Functional description of the gas turbine", Technical document 2009.

[6] A. Kara Ali, B. Babakouya "Study of the alternator launching system, HAMMA II power plant" Master II final thesis, Electrical engineering Boumerdes, 2011.

[7] General Electric Company, "technical document: EX2100e excitation control", Technical document, 2013.

[8] GE Power Systems Gas Turbine "GEK 107415 Revised, June 2000"

[9] G E Company, "Technical Document: LS2100e Static Starter Control, User Guide," Technical Document, 2013.

[10] G E Company, « document technique : Static Starter Analysis », Document technique, 2013

[11] GAMA POWER, "technical document: General single-line diagram" KDM / SPE, 2013.

[12] General Electric Company "technical document: LS2100e static starter control, Product Description", 2013

[13] G E Company, "Technical Document: LS2100e Static Starter Control, User Guide," Technical Document, 2013.

[14] A. MAHMOUDI, "Alternator operation and operation", Technical School of Blida 2009.

[15] B. BAYALA, "Electric machine", continuing education - senior technicians, electrotechnical engineer. 2009

[16] HASNI Mourad "Parametric and Structural Identification of Synchronous Machines by Application of Various Excitation Signals" Doctoral thesis, Ecole Nationale Polytechnique, 2007.

[17] GE Power Systems Gas Turbine “GEK 107415 Revised, June 2000”

[18] ABB Switzerland Ltd « MEGADRIVE-LCI Large adjustable-speed synchronous motor drives »

[19] IEE Proceedings B - Electric Power Applications « 1993 »

[20] Power Electronics Handbook (Fourth Edition), 2018

[21] Village Electrification (SKAT, 1992, 128 p.)

[22] Ned Mohan 2010 « LCI »

[23] EEEGUIDE | Online Electrical and Electronics Study