Load Management of Industrial Facilities Electrical System Using Intelligent Supervision, Control and Monitoring Systems

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Abstract

The continuity of electrical energy is the main subject among all others affecting operational sustainability in industrial facilities. Therefore electrical system and its extensions shall be controlled, supervised, monitored and protected by intelligent systems. Hence, it is necessary to incorporate into electrical system required resources and hardware that will enhance the safety and sustainability of electrical energy by means of utilizing all available economical and technical means. In this regard; industrial facilities, along getting fed by national grid, install stand-alone production units too. However, electricity systems involving multiple energy production resources need to be run and controlled by smart systems that do not require technical manpower interference in order to comply with economical constraints, governing laws, regulations, etc. and be able to take prompt and correct decisions. Therefore, electricity systems should be enhanced with necessary prompt intelligent decision-maker and performer subsystems, which will continuously monitor, supervise, control and record electrical system and extensions and ensure system sustainability in case of occurrence significant change in the whole system. This article aims to illustrate all required smart systems that ensure sustainability and safety of electrical energy, complying with governing laws and regulations and an application regarding supporting systems in an industrial facility.

Key words – Load Management, Supervisory control and data acquisition system, load shedding system, load control system, frequency control.

1. Introduction

Continuous and uninterruptable electricity supply in the industrial facilities is possible only with intelligent very fast operated monitoring, supervision and control systems, which execute correct operation, function of compatible systems and shut down of electrical system partially to protect against overall collapse if necessary. These are possible with applying today's computing and control equipment and technique to reduce energy cost and improve profits [1]. Today it is also easy for industrial facilities to collect huge amount of real-time data from primary level devices either with a protocol or hardwire given through the following paragraphs in order to use for control, monitor, supervise and analyze purposes.

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Supervisory Control and Data Acquisition System (SCADA) is one of the major components of the industrial facility electrical system covering generation, transmission and distribution operation in harmony. SCADA system is not only related with above described systems but also with, the Uninterruptable Power Supply System (UPS), Variable Frequency Driver (VFD) and Diesel Generator (DG) monitoring and controls as well. In addition to control, monitoring and supervision of electrical system, there are complementary systems that maintain electrical energy quality, continuity and safely operation in case of any kind of fault or partial interruptions during island or parallel operations with national grid. Those systems require totally independent operation from SCADA to achieve the system safety, like load shedding system and load control units.

This paper introduces an overall explanation of intelligent control, monitoring and supervised systems installed at a very big petroleum refinery in Turkey. The paper is also introducing communication protocols which are used for data transfer between individual systems.

2. Supervision, Control and Monitoring of Electrical Systems

2.1. General

Ensuring safe, continuous and high quality energy provision and distribution is possible with continuous intelligent monitoring, supervision and controlling systems and isolating faulty parts if necessary. Widespread electrical systems and relevant components in high energy-consuming facilities such as refinery, petrochemical and iron-steel industrial plants can meet aforementioned functional expectations only if control, supervision and monitoring systems are well-defined, set and operated in a good harmony. The system and components to be used load management of industrial faculties electrical system covers all layers of smart grid infrastructure shown in Fig.1 [2]. According to the smart grid architecture, smart grid adds three key innovative components on the physical energy grid which are communication, computing and information and smart application [1]. Today, all components of smart grid architecture are applicable to any industrial facility electrical system. Three computing systems are used in this study. Load management applications and software run inside these systems to perform system monitoring, control and supervise actions. The computing systems are connected by communication links to each other for normal and emergency operation of electrical system.

These are [3];

- Supervisory Control and Data Acquisition System,
- Load shedding system (LSS),
- Load control system (LCS),

Electrical system of industrial facility to whom above intelligent systems are successfully applied, is shown partially in Fig.2. The heavy loaded, complicated electrical system covers seven substation buildings included low and medium voltage switchgears and motor control centers with interconnection lines. 154 kV SWG (switchgear) with transmission lines and power transformers are installed in one of the seven substations. There are also, two gas turbine generator sets and one steam turbine generator set to provide continuous electrical energy demand of the refinery in addition to national grid power supply lines connections.

Connection and communication aspects of the systems for the control, monitor and supervise of the electrical system including LSS and LCS are shown in block diagrams in Fig. 3. Load management system covers a number of substation including low and medium voltage switchgears and motor control centers with interconnection lines. There are also stand-alone two gas turbine generators and one steam turbine generator sets to provide continuous electrical energy demand of the refinery in addition to national grid power supply lines connections.

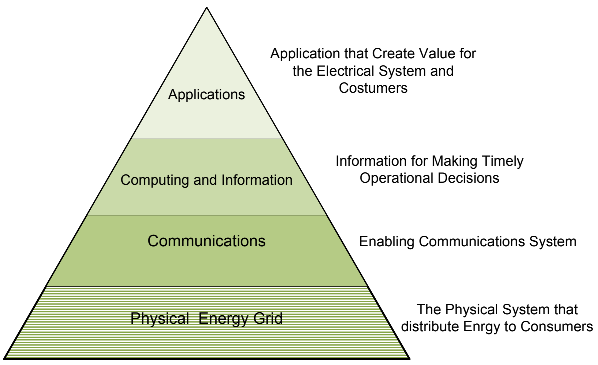

Fig.1. Smart grid infrastructure

2.2. Supervisory Control and Data Acquisition System Components

SCADA is responsible for controlling, supervision, and data acquisition of the industrial facility electrical system events including high voltage transmission, generation, and primary and secondary distribution systems. SCADA also controls, monitors and supervises low voltage systems at incomings, tie-breakers and diesel generators levels. SCADA executes the following functions mainly [1], [3].

- Complete information about the plant. Monitoring of circuit breakers status, source of feeding, and level of the consumed power.
- Information about the operating values of the voltage, frequency, current, power, energy, power factor.
- Information about transformers, on-load tab changers and load feeders.
- Electrical system control by opening and closing circuit breakers, isolation and earthing/grounding switches.
- Protective system information, including alarms, event and history recording.
- Information about the quality of the system (frequency, current, voltages, power factors, flickers, etc.).
- Metering and monitoring turbine generators.
- 11 kV motors start permissive.
- Time synchronization, including all relays and system connected with the SCADA system (DCS, LCS, fault recorder and load shedding). This function allow the analyze of the alarms, event and faults reports, in the same time base.

2.2.1 Supervisory Control and Data Acquisition System

In order to achieve the functions mentioned on the previous paragraph, SCADA system receives numerous signals through either one of international accepted communication protocols or hardwired connections and process, then produces an output for execution. Control, supervision, monitoring and alarm functions of SCADA has only be executed by using equipment/systems installed at four different levels explained as below.

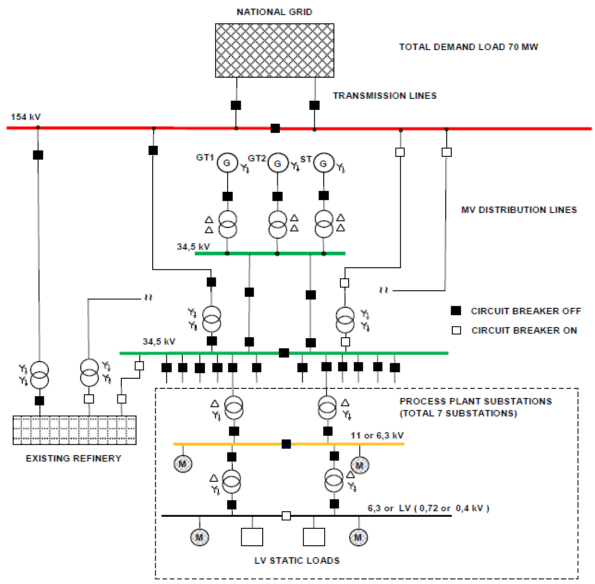

Fig.2. One line diagram of industrial facility electrical system showing generation, transmission and primary distribution systems

- 1st level, field data acquisition;

This includes hardwired and communications signals from final devices to the Remote terminal units (RTU) located at substations.

The data acquisition necessary for controlling, monitoring, supervision of electrical system is achieved by the primary devices to be installed at side. The devices at this level is the first electrical sensors. Devices either directly or through the communication links are transferred the data to upper levels. Primary devices can be a contact or a relay or transducer. The number and type of primary devices depends on information

requested are connected to each electrical equipment. The data or information to be sent to SCADA from field device are transferred to the nearest remote terminal unit (RTU) through communication links or hardwired connections.
The date transferring media to be used filed devices are grouped as follow;

- Multifunction relays communicate with RTU´s through fiber optic connection using standard protocol IEC-61850. The communication in loop configuration is with redundant connection. All relays (devices) have two dual communication ports. All required information (circuit breaker status, switch status, etc.) is concentrate in the relays, in order to be accessible from SCADA, also open and close command will be executed by using relays capabilities.
- Other field devices (UPS, EDG, etc.) without IEC-61850 protocol, communicate with RTU´s through RS-485, using Modbus protocol.
  Automatic voltage regulators communicate with RTU´s through serial connection using standard Modbus protocol.
- Field devices without communication capabilities (transformer protection, etc.) use dry contacts to bring the information to the RTU.

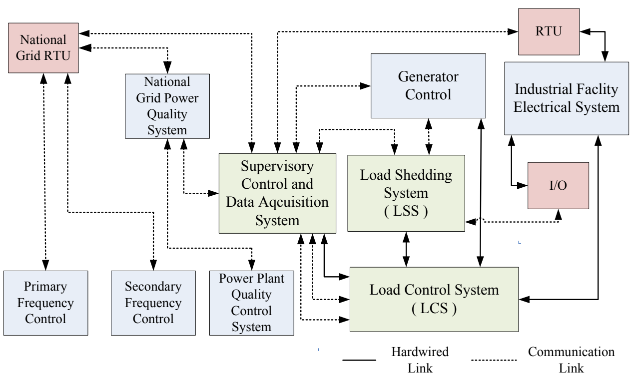

Fig.3. General communication interface topology of intelligent supervise, control and monitoring of industrial facility electrical system.

- 2nd level, processing units;

Remote terminal units (RTU) execute the interconnection between the field equipment (Level 1) and the SCADA system (Level 3). RTU is designed fully redundant. Connection to SCADA servers is made through O-ring fiber optic cables. In case of any failure in any card, redundant partner takes over the communication. Additionally all RTUs will have redundant connection with all SCADA servers, in order to guarantee the information availability in both systems.

- 3rd level, SCADA and human machine interface level (HMI);

  This covers all microprocessors where resides the electric power system database, system management and event recorder in order to perform the SCADA functions indicated above. In addition, equipment required for operator interface with the system and new human machine interface (HMI) screens and control desk are included in this level.

- 4rd level, SCADA externals connections;

This covers all externals access / connections with the SCADA system. Following connections are considered:

- DCS process link: One (redundant) communication link is considered in each substation in order to be able to transfer any information useful for the process operators. Firewalls are considered in order to avoid any no authorized access or any interference between both systems (IP address conflict.)
- LCS communication link: One redundant communication link is considered between SCADA and LCS system, in order to have the SCADA alarm and event list actualizations. Generators operation mode and island mode detection are hardwired connected from load shedding system (LSS) to LCS system.

2.3 Load Shedding System (LSS)

Load shedding system is a hardwire platform in charge of load shedding and some load sharing functions. Two independent subsystems run inside of this platform.

2.3.1 Identification Network Configuration (INC)

The aim of this control is to identify through all breakers status, which is the current network configuration, in order to adjust the load sharing /load shedding controls functions.

An alarm defined as “actual network configuration is not in database and cannot be recognized” will be generated when any operational configuration cannot be identified. Under this alarm, load sharing and load shedding control shall change to manual mode.

Load shedding PLC will interchange information with the load control system (LCS) to be installed as a part of intelligent load management system. With these signals, LCS will be available to evaluate the electrical network configuration (circuit breakers statuses), power flows (transducers) in order to share the load between the generators and national grid.

2.3.2 Load Shedding Module

Load shedding has two operational criteria; load shedding due lack of generation capacity (main) and load shedding due under frequency (backup). Any of these criteria starts a sequence of load shedding and/or alarming, in order to restore the power system stable operational conditions [5].

Load shedding due lack of generation capacity: The aim of this control is to anticipate a frequency drop in case of any power system network configuration change results on more load that the available generation / interconnection power sources.

During a lack of generation power condition, a fast load shedding will start. Magnitude of load to be shed shall be based on comparison between the capacity of running generator, maximum capacity of interconnection power sources and the active power demanding of industrial plant.

Above comparison is done (in advance) for each possible network configuration and possible contingencies, as result as soon as load power becomes larger than the generating / interconnection capacity, LSS will order to trip a pre-selected groups of loads in order to obtain the balance.
All load shedding shall be strictly in accordance with the preset load priority sequence and limited to the minimum necessary. In base to identification of the network configuration (INC) load shedding system shall select the load, generation and interconnections line to be involved in the portion of the electrical system that will be affected by the under frequency.

Load shedding due under frequency: The aim of this control is to avoid the power system collapse, due under frequency conditions. Three cases are possible:

Case 1: When under frequency is detected during running generators and national grid in parallel, decoupling relays in relevant switchgears shall order the separation from national grid (area disconnection). To do this disconnection all interconnection lines with national grid are opened. After disconnection from national grid, load shedding based in lack generation capacity becomes activated depending of the original network configuration and the resultant one.

- Delay times type 1: To support the under frequency connected to the national grid, during these times the primary frequency control (in LCS) is activated in order to release some extra power to the national electrical system (all consumers with generators will do the same). The times type 1 depend of the magnitude of under frequency, generators characteristics and nationals regulations.
- Delay times type 2: After disconnection with national grid, in function of the under frequency value and the generator characteristics, the delay times type 2 had been calculated in order to shed quantities of load that allow the generators remain in the synchronous conditions.

Note: If the frequency conditions are reestablish (inside times type 1, the national electrical grid administrators can ask to activate the secondary frequency control. The aim of this control is reestablish the power flows in the national system.

Case 2: When the under frequency is detected and refinery is disconnected from national grid , the LSS will initiate a sequence of load shedding steps, one after another in order to recover the frequency (balance between load and generation capacity).
After the operation of load shedding system, it's not possible to start again motors/lines tripped by LSS. Operator gives a reset command to LSS in order to be able to close the opened lines and start the motors again. This LSS has latch function that doesn't permit any attempt to start/close (reacceleration, emergency shut down system, distributed control system or local start).

Case 3: When both refineries are connected only by one 34.5 kV line, and the under frequency condition is detected, load shedding produces order the separation (open the remaining 34.5 kV line), and each refinery has his own load shedding scheme.

After the operation of load shedding system, it's not possible to start again motors/lines tripped by LSS. Operator gives a reset command to LSS in order to be able to close the opened lines and start the motors again. This LSS has latch function that doesn't permit any attempt to start/close (reacceleration, emergency shut down system, distributed control system or local start).

Load shedding priority groups and shedding steps are decided together with process and electrical engineers.
Manual load shedding is also possible in order to allow the operator the manual load shedding steps.

Load shedding system has the tools to allow the operator remove or include load in the different load shedding blocks. Option to remove load temporary shall be possible (by pass), this option only can be executed in load shedding workstations (local bypass is not allowed). All access to LSS programs and settings are password protected.

2.3.3 Faster Load Shedding Function

Load Shedding PLC will define the generators operation mode. Mode selection will be done in base to the network configuration.

Generator priority list shall be created in load shedding PLC, in order to define which generator will take the frequency control, according the network configuration. Load shedding PLC shall have tools, in order to allow the operator the easy priority list modification.
When the refinery is connected with national grid, the frequency will be managed by national grid. All generators are adjusted in load mode or steam generation mode (if it is applicable).

When industrial facility electrical system is disconnected from national grid, the frequency will be managed according the generator priority list. This list shall have all generators.

• Generators out of service will not be taken in account (system will take the next generator in the list).

• Load shedding PLC shall have tools to update this list. List modification will be implemented in the load control PLC only after operator confirmation.

There are two main operational modes for turbo generators in which load sharing will be required:

Mode 1: Industrial facility electrical system isolated from national grid:

Under any network configuration that cause an operational mode that industrial facility generators running in parallel amount them but isolated from national grid, the load sharing shall:
- Detect the network configuration and the operative mode, including the extension of the system fed by the turbo generator.
- The turbo generator with higher priority in industrial facility electrical system will be adjusted in speed control (isochronous) to lead the frequency. The other generators

will be adjusted in load mode or steam control (only applicable for STG).

In case of loss of the selected turbine (the one controlling the frequency); the following turbogenerator in the priority list will be adjusted in speed control (isochronous).

Mode 2: Industrial facility electrical system connected with national grid
Under this network configuration the frequency control of the system is provided by national grid. All generators shall be adjusted in load mode or steam Control (only applicable for STG).

Following operational modes will be available for each generation type:

- Gas Turbo generators: Load mode.
- Steam Turbo generator: Load mode / steam control.

2.4 Load Control System (LCS)

The aim of this control is to verify continuously the load power demand of refinery, along with the generated power and the power interchanged with national grid, in order to allow the operators maintain the power system within the maximum and minimum ranges [6].

Load sharing control based in DCS system shall have communication links with load shedding PLC and SCADA servers, in order to receive the required electrical system information (circuit breaker status, generator modes and measurements).

The functions to be performed by load control unit are as follow;

- Load sharing,
- Power factor control,
- Load frequency control

2.4.1 Load sharing

Electrical energy demand of industrial plants, export or import from the national grid are controlled by the load sharing module of the load control system. This module also distributes load demand of plants and national grid requirement between generators and transmission lines. Load sharing module achieves load distribution between power sources (generators and national grid) and consumers with the help of data received directly (digital or analogue) or by communication links from existing systems (SCADA or load shedding PLC).

Load sharing module fulfills the load distribution in accordance with generators' island or national grid parallel operation.

Normally the steam turbine generator (STG) electrical energy generation is limited by required steam consumption (in refinery environments, steam generation continuity is important than the electric production). In consequence the STG will be taken take into account only to close the power balance, but the change of power (increase or decrease) will be shared between the gas turbines generator. Only in case of lag generation the LCS system will require change in STG power setting.

- *Interconnected with national grid*

  In this operation mode, load sharing control regulates generators according with the target import/export power limits prefixed between the industrial facility electrical energy demand and national grid. Regulation is done within the capability of the generator in parallel with the national grid. If the settable export or import power from national grid is reached, this control generates commands to the generators to maintain the import or export power within the established limits. Load sharing distribution between generators is done, taken in account the rated power for each generator and the generator operation mode. Load sharing is done in base to the available power in each generator. Generators are in load mode and frequency is defined by grid.

  The power to be import / Export are managed by a 24 hours preprogram table, in function of this table each hour the system will change the target to be imported/ exported. It is also possible to fill the table 24 hours in advance and also change edit in real time.

- *Island mode operation*
  With the system isolated from national grid, load sharing control regulates the generators according with the generators rated power. Only one generator is operated in speed (isochronous) mode to maintain frequency and remaining ones in load mode. Reactive power is adjusted through the automatic voltage regulator (AVR) in each generator. When power demand of the isolated system exceeds the generator/generators capability and frequency cannot be maintained, the load shedding control system is activated for shedding the overloads until power generation meets industrial facility electrical demand loads.

2.4.2 Power factor control (PFC)

The purpose of this control is to verify continuously the reactive power the interchange with the national grid company (national grid) and the reactive power produced for each generator.

Three selectors will be available on HMI´s for each generator (system control - generator - manual control):

- *With the PFC on system control:* If the total import power factor departs from the set point, this control function generates commands to raise or lower their reactive power production, in order to take the system power factor to the set point.

- *With the PFC on generator control:* If any generator power factor departs from his set point, the control generates commands to raise or lower their reactive power production, in order to take the generator power factor to its set point.

- *With the PFC on manual:* If any generator cannot reach the power factor set point, the system generates an alarm, indicating the generator name, the real active and reactive power, the operator rises by manually the power factor to set point.

2.4.3 Load frequency control

The purpose of this control is to help the national electrical system to maintain the equilibrium between generation and demand power [7]. If this control is not enough, area separation or automatic load shedding will be performed.

Load frequency control must be executed in coordination with all members (power generation plants) of the specific electrical interconnected systems (control area). Each member must contribute to the disturbance correction in accordance with its respective contractual contribution. In this application, control area shall be coordinated with national grid.

Primary and secondary frequency control shall be implemented by LCS and gas turbine generators control according with Turkish regulation (Law no. 4628 Electrical Market Grid Code dated 26-11-2009) and electricity market ancillary services regulations. .

Primary frequency control: Gas turbine generators controls execute automatically the primary frequency control in function with frequency variation. Software program on LCS, registers and delivery all variables on the frequency, power and generators operation to national grid. Power Generation Company is responsible to transfer all information to national grid.

The aim of this control is to maintain the frequency near to 50 Hz (within strict limits) [7], operating over the generators speed, this control is influenced by the generators inertia, the generators control characteristics (generators respond delay time) and the power reserved for the primary control.

Seconder frequency control: LCS executes the secondary control in generators. The aim of this control is to return the frequency to the nominal value (50 Hz) after primary control activation [5], its principal function is to restitute the reserve primary power and return the power interchange to the programmed values. The secondary control will be activated after primary control (adjustable time from seconds to 15 minutes).

3. Conclusion and Recommendations

Electrical system control, monitoring and supervision inside industrial facilities are so complicated due to generation, distribution and transmission system operations affecting each other. Any quantity or quality deviation in one of power sources or loads will automatically affect remaining sources and loads. In addition to plant requirements, electrical system shall also meet national grid necessities, such as maintaining frequency predetermined limits and support active, reactive power. The load management system established in the refinery has capability and availability to meet both refinery demand and national grid requirements with real time, high speed fulfillments. Although the load management system and its integration seems to be very complicated, trained personnel overcome possible operation difficulties after very well organized test programs. One of the main advantages of the system is to not require any critical operator decision. The observations from start-up till that time shows that; old electricity supply problems drop behind, and the frequency of the energy interruptions is so rare. The electricity system is more reliable and improper operations are prevented by logical barriers starting from that moment.

In addition to all above, the intelligent load management system has the following main features, too;

- Real time monitoring due to high speed data transfer,
- Intelligent alarming capabilities for early maintenance,
- Accurate load management for generators loading during export and import operations.
- Save money by avoiding any penalty from the utility.
- Keep voltage and frequency within the allowed limits
- Catching and analyze any fault happened in the system.
- Fulfill electrical system operator requirement.

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