Steps for Industrial Plant Electrical System Design

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Abstract

The main objective of this study is to determine the design steps of an industrial plant electrical system in the light of energy availability, continuity, safety and economic equipment selection. This study is not only dealing with design steps, but also analyzing alternative solutions with their positive and negative impacts. Steps to be given in the following paragraphs will reduce possible system design delaying, equipment selection and quotation.

As it is known, the engineering data and selected configuration during design stage will be used for electrical system cost estimation. The final equipment cost will be obtained after detailed engineering design completion. But differences between estimation and final costs are not so high if a methodology is followed as It is given in this study.

1. Introduction

The sections given below will give a guide the project engineers and organizations to design the required industrial electrical system under safe, operative and economic constraints in a short period successfully. The design steps have been developed by writer with many years of experience in the heavy industry plants [1, 2, 3] Although of interest to anyone seeking information on more simple electrical systems, the study is primarily intended for use by individuals knowledgeable in the engineering fundamentals who require specific guidance concerning currently accepted practices [4, 5].

In the design of an industrial electrical system, the following main steps shall be performed;

- Load determination
- Power provision
- Electrical distribution
- Equipment selection
- Studies

2. Electrical Load Determination

The size and distribution of electrical energy consumed loads of the dedicated plant shall be determined before to start electrical system design. The size and type of the electrical energy consumed loads are generally defined by process or industrial plant characteristics at the beginning [6, 7, 8]. The major electrical energy consumers are generally motors and heaters which are selected according to driven equipment and process variables. Electrical design engineer receive such information from mechanical and process engineers to reserve necessary power for dedicated equipment.

- The main electrical consumers in a standard size industrial plant are;
- Motors which will drive pumps, compressors, air coolers, fans etc.
- Electrical heaters to be used for heating and drying liquids, air, different products etc.
- Electrical heat tracing to keep liquid temperature constant and to protect liquids against frozen.
- Lighting system components
- Instrumentation, including computer and auxiliary system loads,
- Socket outlet loads
- Package systems, such as lube oil, injection etc. loads
- HVAC loads

3. Power Supply

This section describes necessary needs for supplying electrical energy demand of above mentioned loads [9, 10]. The equipment, system and devices to be used for provision of electrical energy from sources to consumers are reviewed under safe, reliable and economic conditions. The general aspects, from the point at which power is introduced into the industrial plant to the points of utilization, are covered in this section.

3.1. Power Sources

3.1.1 Generated Power

Although is not reliable operation mode, but due to economic, technical or very strict governmental regulation reasons, electrical energy requirement of the industrial plant is produced totally from one or generally more than one Generators without connection to a public utility system. Generators, depends on process needs can be driven by steam or gas turbines or both. The main contingency in this configuration is the system capability to start the highest rated motor while all remaining loads are in operation. Turbine types, generator electrical characteristics including size and bus bar arrangements need further investigation for final configuration.

3.1.2 Import Power

In this configuration, all electrical energy requirement of plant is provided from totally utility sources through incoming lines with a sufficient capacity. The reliability, line voltage and number of the feeder connection of the utility to the industrial plant are the main subject to be considered for electrical system design.

3.1.3 Combination of Generated and Import Power

In order to increase energy flow reliability of electrical loads, plant owned generators are operated in parallel with outside utility sources. Any general or partial failure in one of power sources, generators or utility continue to supply electrical energy demand of industrial plant without any shut down. In this operation, depending energy trade agreement, electrical power can be export to or import from utility sources.

3.1.4 Emergency Power Supply

In order to provide necessary energy demand of the critical equipment during partial or general electrical failures, two types of power sources are inserted into main electrical system.

- Uninterruptable power sources: They can be AC or DC or both. But they are generally battery back upped. In normal operation, critical loads are supplied over inverter which takes power from the AC lines through a battery charger and batteries. If the ac power fails, the batteries continue the feed the inverter to supply critical loads.

AC critical loads are ;

- Distributed control systems.
- Emergency shutdown systems
- Instruments
- Gas detection systems
- Fire alarm systems
- Computer loads
- SCADA

DC critical loads are;

- SWG , MCC etc. control, protection, metering and measuring circuits
- CB spring charge motors
- Very critical lube oil pumps

- Emergency generators: These additional power sources are started automatically when the normal power supply fails and to be operated for a limited duration and selected critical loads. These loads can be some motors for safety operation or safety shut down, partial lighting system and ac, dc uninterruptable power sources.

4. Electrical Distribution System

The equipment to be used both the electrical energy delivery from the generating and/or outside utility sources to the consumers and may be through of the primary or secondary distribution type, or a combination of both systems. In general, the system arrangements at the primary voltage level are suited to widespread isolated loads, whereas system arrangements at secondary or utilization voltage level are sited to the concentrated loads.

- Primary distribution systems, which carries the load at higher than utilization voltages from the main distribution centers (or generating or imported power centers) to the point where the voltage is stepped down to the value at which the energy is utilized by consumers.
- Secondary distribution, which includes that part of the system operating at utilization voltages, up to the meter at the consumer's premises.

The arrangement the primary or the secondary distribution system are governed by a number of factors such as service continuity, flexibility, regulation, efficiency, operating costs, and investment cost. The reliability of the industrial plant will also have bearing on the system arrangement selected. The maintainability of equipment should be carefully considered because it affects all of these factors. There are two basic arrangement based on the connection of main circuits to the power sources, which are radial and loop systems.

The radial-type system is the simplest and the one most commonly used. It comprises separate feeders or circuits “radiating” out of the substation or source, each feeder usually serving a given area. The feeder may be considered consisting of a main or trunk portion from which there radiate spurs or laterals to which distribution transformers or consumers are connected. The transformers or lumped loads are usually connected to the primary main through, depends on supply voltage, fuses, MCCB, moulded case circuit breaker, MV CB etc., so that a fault on lateral will not cause an interruption to the entire feeder. The main disadvantage of this system is that; In case of protection device failure or a fault develop on the feeder main, the CB at the substation or power source will open and the entire feeder will be de-energized.

The loop or ring systems are designed for restricting the duration of interruption employs feeders. In these configuration, there are generally a two way primary feed for transformers or consumers. Here, should the supply from one direction fail, the entire load of the feeder may be carried from the other end, but sufficient spare capacity must be provide in the feeder. This type of system may be operated with the loop normally open or with the loop normally closed. Systems that utilize multiple supplies, loops and/or ties are more complex. Because of the number of relays, switches and interlocks required, these systems necessitate careful engineering to avoid shutdown because of equipment failures or improper operation. Although this system is more reliable, It is more expensive and operation is difficult.

The easiest and widely used system to understand, operate and troubleshoot in industrial plants is the simple radial system.

5. Equipment Selection

The electrical equipment to be used for the industrial plant electrical system can be grouped in two main heading which are The equipment to be used for the delivery of the electrical energy from the generating and/or outside utility sources to the loads,

The equipment to be used for safe, reliable, flexible, efficiency and continuous operation of plant by converting electrical energy to another type of energy, such as mechanical, heating, etc.

In addition to above the two groups of equipment, there are various type of complimentary systems which are necessary for safe plant operation such as grounding, lighting, lightning etc.

6. Components to be used for Electrical Energy Transfer

These components for transferring energy from power supply sources to the final consumers are static; they have not any moving part during power flow. Some of or all of them can be used for industrial plant electrical system design. They can generally selected indoor type for industrial plant electrical systems.

6.1. Switchgear

Medium Voltage Switchgear: In order to switch the power flow and interrupt the faults and overloads occurred on medium voltage downstream circuits or loads, the special designed and assembled electrical equipment, named switchgears are widely used [8, 9, 11]. They contain one or more metal clad compact modules with equipped control, metering, protective and regulating devices with the associated interconnections and supporting structures. The heart of the switchgear is the circuit breaker. Associated with the circuit breakers, are necessary buses, disconnecting devices, current and voltage transformers. Switchgear is generally used for control of generators, large motors, transformers, feeders and other large electrical equipment. Circuits breakers used in MV use oil, vacuum or SF6 as the interrupting medium. Medium voltage Buses are insulated by air or gas. Medium voltage switchgear together with circuits breakers are selected in accordance supply voltage, nominal load and possible maximum short circuit current. They can be fixed or draw out type.

Low Voltage Switchgear: The switching of the power flow and interruption of the faults and overloads occurred on low voltage downstream circuits or loads are controlled by low voltage switchgears. The preferred construction is metal enclosed, using generally air break, very rare vacuum for higher loads, drawout type low voltage power circuit breakers. In addition to low voltage air insulated circuit breakers, the molded-case circuit breakers are widely used in low voltage electrical systems by installing in panel boards, switchboards and switchgears. The basic advantage of the molded-case circuit breakers do not depend on external relays for sensing overloads and faults. Low voltage switchgear together with circuits breakers are selected in accordance with nominal and possible maximum short circuit current. Low voltage switchgear which contain the majority of Low voltage motors, are specially named as motor control center (MCC).

6.2. Transformers

Transformers depends on industrial plant electrical demand size and the location of the distributed electrical loads, are used to isolate different voltage systems, such as HV/MV, MV/MV, MV/LV from each other and reduce or increase voltage to their optimum utilization voltage levels. They are used to transform generated or utility system voltages to the plant distribution voltage levels or to provide the utilization voltage level for all medium, low voltage rated plant loads. In case of power generation plant exist in the plant, transformers are selected step-up type. Transformers may also be selected for two way energy transfer of economic plant operation between internal plants or plant and external utility sources, such as national grid. Transformers used in industrial plant electrical system design are distribution type and they are selected in accordance with supplied load types and duties, environmental conditions, location, voltage variation etc.

All MV/LV distribution transformers of the new industrial plant electrical system is selected with the following mechanical characteristics, although to be many options.

Oil filled insulation in expandable tank, natural oil circulation with natural cooling, generally fixed load but shall have capacity for big motor starting while fully loaded, off-load tap changer under shelter installation.

On other hand, HV/MV and MV/MV transformers of the new industrial plant electrical system is chosen a little different than MV/LV transformers which are oil filled insulation in fixed tank with oil expansion reservoir and forced cooling in order to reduce higher sized transformer cost. The majority of them are equipped with on-loaded tap changers which give flexibility to keep voltage drop in acceptable limits during big motor starting by increasing secondary side voltage.

6.3. Motors

This paragraph is intended to serve a basic guide in the selection of electrical motors which are the highest energy consumers in industrial plants. The motors which convert electrical energy to mechanical energy to be driver of pumps, compressors, air coolers, fans etc., are selected in accordance with driven load shaft power. The most widely used motor type in industrial constant speed applications is squirrel cage induction due to simplicity, reliability, adaptability and maintainability, the synchronous type motors are preferred principally in larger loads and operable lower speeds. DC motors are selected for small size and very critical loads, such as lube oil pumps. Due to economic reasons motors up to 400 kW are selected in the availability of low voltage range and higher size ones are preferred one or two level medium voltages, such as up to 2 MW, a standard system medium voltage and above higher rated loads, another standard higher medium voltage.

Where necessary, some or all of the following basic requirements shall be taken into consideration for each specific motor selection;

- Insulation class and allowed temperature rise,
- area where the motor to be installed; inside, outside, classified (gas, dust etc.), safe, wet, inside any kind of medium, such as water [12].
- starting method and suitability for inverter operation,
- cooling method,
- bearing type,
- duty cycle, loading and service factors,
- space heater need,
- vertical or horizontal erection,
- efficiency class, preferably higher classes where available

6.3.1 Motor Starting Techniques

In order to reduce voltage fluctuation, generally as voltage drop in electrical system due to starting (in-rush) current of motors during acceleration, one of the following starting method can be selected ;

- reduced voltage starting by autotransformer, reactor or resistor
- star-delta (wye-delta) starting
- solid-state (soft) starting
- capacitor assisted starting
- wound rotor control starting
- starting with VFD

6.4. Adjustable Speed Drivers

Due to operational and economic reasons, the speed adjustment of air, gas and liquid flow in industry is widely controlled by conventional control valves, dampers and gearbox while motor is operated at constant speed. In order to save energy while flow speed controlling, more efficiency and more sensitive equipment named variable speed drives take place in all industrial and process applications. Although the application of adjustable speed drives are somewhat limited, their use in industry is gaining popularity. Pumps, compressors, blowers, air coolers, fans, conveyors etc. equipment applications may allow changes in flow by speed control systems without utilizing conventional control systems. Elimination of conventional control systems may result in added energy and investment savings.

The wildly used variable speed drives in industry is made of electronic components, shortly called variable frequency drives. Magnetics speed drives, although are not common use, they are also used for speed controls. For higher size loads, mechanical speed drives, like hydraulic coupling may be preferred due to long life time, high reliability and maintainability

6.5. Power Factor Correction

Reactive power is essential to the operation of AC electrical equipment but its generation and transfer to the consumed loads affects the operation of the electrical system. In order to increase total real power generation, transmission and distribution capacities, reduce energy losses and voltage drops, reactive power shall be generated by special devices where or near this power is consumed. Since reactive power generation increases the power factor of load or entirely distribution or transmission lines, this improvement technically is called "power factor correction". The main reactive consumers in industry are squirrel cage induction motors, lighting lamps ballast and transformers. If synchronous motors' excitation is adjusted to unit power factor, the motors don't consume any reactive power. The main elements in reactive power factor correction system are shunt installed capacitors.

For power correction, depends on each individual application, there are individual, grouped or centralized power factor correction applications. In order to adjust desired reactive power requirement of the electrical system, the grouped and centralized power factor correction systems are designed in steps of capacitor banks.

6.6. Distribution Lines

The distribution of electrical energy from power generation centers or utility sources to the consumers are made by overhead or underground lines. Although the extension distribution lines of industrial electrical system may be overhead lines out of battery limits, due to safety and operational reasons, distribution lines between main and sub distribution centers are preferably designed by above or underground cables. The final connections between sub distributions centers, controllers, panels etc. and loads, consumers are always are above or underground installed cables. Depends on load size and distance, lines can be one or more steps medium and low voltage levels. There are many factors effecting line size. Although medium voltage lines size are checked basically against energy losses, low voltage lines are checked with voltage drops. Mechanical factors and environments conditions are also taken into consideration for final conductor size selection. XLPE insulation material in almost every voltage level are preferred for cables due to give opportunity loading cables in higher capacity. Upon usage conditions, such as fire resistance, under sea, wet, chemical polled areas etc. special cables can be manufactured.

6.7. Others

The systems which are not directly affect industrial electrical system design but necessary for safe, reliable and continuous plant operation, need to be taken into consideration.
The complimentary sub electrical systems to be provided for industrial plant electrical system are as follows;
- Grounding
- Lighting
- Ligthning

7. Studies

The design of the industrial electrical system requires continual and comprehensive analyses to evaluate the suitability, the adequacy, strength and performance of the selected electrical system and equipment. Therefore the following studies shall be partially or completely performed depends on electrical system size. The results of computer model analyses for instance voltage drop calculation show that the majority of the initial requirements are met [13].

The studies and the reason behind them;

- Load flow calculation: To check voltage drop, equipment loading and relay setting.
- Short circuit calculation: To check equipment strength and relay setting.
- Stability calculation: To check motor and generator behavior after any perturbation caused either by operations or faults.
- Motor starting study: To check the system adequacy for the highest motor staring.
- Harmonic study: To check the harmonic levels and if necessary to take measures the elimination their affects.

8. Conclusions

The steps given above has been followed in many medium sized industrial plant electrical system projects successfully and the systems are now in operation without any major problem. In each of above steps, standard utility construction techniques are combined with industrial design to meet requirements of the system. The use of computer based system design modelling techniques, software programs are necessary for proper design of electrical system and adequate equipment selection. Available computer models give accurate picture of the industrial plant electrical system before plant completion and operation.

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