Design Criterias for Power Supply to the New Refinery

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Abstract

Due to the limited availability of known crude oil reserves, the demand for petroleum products has shown that high demand for petroleum products is due to a high rate of increase in the petroleum demand emerging economies. In order to meet that demand with less energy consumption and low investment cost together with higher power supply continuity, lots of design criteria has been taken into consideration for the new refinery's electrical system design.

The new refinery will meet the increasing demand of diesel consumption of Turkey. Diesel is more economical in Turkey as well as all over the world. The new refinery will process "Fuel Oil" produced in the existing refinery without export additional Crude Oil.

Unlike current Refineries, the new Refinery will be mostly operated with electrical energy sources, because electrical equipment is more efficient than steam, except very critical ones. For this purpose, it has been paid special for attention to the selection of the electrical system configuration, the number and type of power supply to the electrical equipment. Such that the design should allow maintaining the continuity and operational flexibility of the system to the highest level and at the same time using less energy-consuming technologies.

In this study, electrical system design criteria for intelligent electrical network operating system of the new refinery which is registered as one of the top three European refiners in terms of conversion rate, is evaluated under the engineering point of view.

1. Introduction

The structure of the new refinery electrical system is determined by a detailed study of the process operation needs, with the aim of ensuring that the required energy from electricity generation to the last consumer, is cheap, high quality, continuous, safe and at the same time minimally affected by the environment

Considering works below, the design of the electrical system of an industrial establishment, which needs an intense energy such as a refinery, requires a detailed investigation in the light of experienced gained [1, 2, 3, 4].

The topics that require special work in the design of the new refinery's electrical system are not discussed further here, as it is a routine work as it is in all engineering works, such as equipment selection, studies, calculations etc.

This study is focused on the following main topics [5, 6, 7],

- Definition of network configuration
- Definition of power plant size, number of generators and generator size.

2. Network Topology of New Refinery Electrical System

2.1. Survey of Existing Network Configurations of Industrial Plants

Concerning the network configuration of the new refinery electrical system, some previous applied heavy industrial electrical system configurations [2, 3, 5] are analyzed in regard to location of power generation, bus coupler position [8] and voltage level.

In Fig. 2.1, each bus bar level is fed by two in feeds. Furthermore, the two bus bar at each voltage level are connected by couplers are normally closed (NC). Thus, in case of fault at one generator, busbar or transformer the load is fed by the remaining equipment, which satisfies the so-called N-1 criterion. In this configuration, there is not any interconnection with external sources including national power network.

In case of a short circuit at a busbar, the short circuit current is increased if the bus coupler is closed, since the fault current is fed from two directions, through transformers.

During motor start up, the voltage drop with a normally closed bus coupler is diminished compared to a normally open bus bar coupler. The generations are at 34,5 kV (through transformers) and 11 kV levels and network structure is radial. Moreover, there is only one low voltage level.

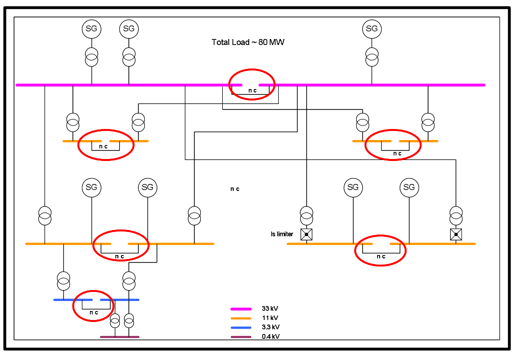


Fig. 2.1

In Fig 2.2, each bus bar level is also fed by two in feeds whereas below 34.5 kV level the bus couplers are in a normally open (NO) position. In case of a fault, the couplers have to be closed. This means that the loads are not supplied for some hundred milliseconds- depending on the types of power transfer switchover. Power generation is centralized at the 34,5 kV level. Again, there is a radial structure with reduced steps at the 10 kV and 5 kV levels and two different low voltage levels, 0,525 kV and 0,4 kV.

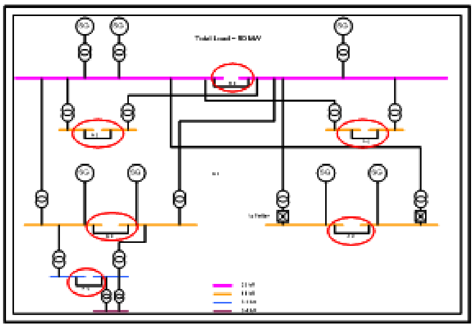


Fig. 2.2

In Fig. 2.3, the industrial plant is not equipped with a power generation at 110 kV. The generation is at the 5 kV level with the generators dispersed at several busbars. If there is a fault at the 110 kV busbar, the dispersed generators have to cover the whole demand of the remaining grid. The structure is not exactly radial. On the one hand, this provides a better voltage stability, on the other hand more (sub) units are affected in case of fault. Furthermore, there are two different low voltage levels.

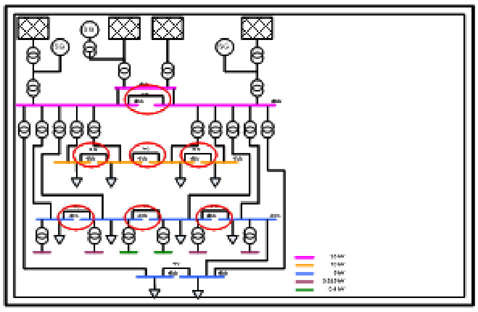


Fig. 2.3

In Fig. 2.4, the power generation is at 6 kV level. In case of a short circuit, this yields more elevated short circuit currents. Therefore, the power generation unit has to be equipped with short circuit limiting reactors. The structure is radial with several subunits, which increases the cleaning time of potential fault. For that reason, cable differential protection is installed.

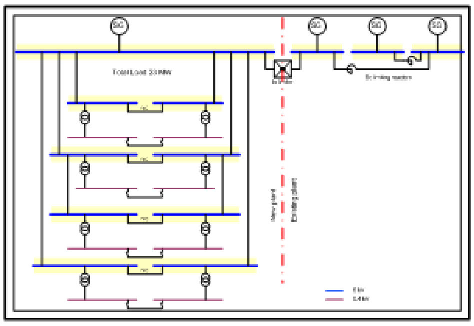


Fig. 2.4

2.2. Selected Electrical System Topology of New Refinery

The advantages and disadvantages of each configuration developed and applied for the supply of equipment in different but similar industrial plants at various times in various countries above have been made in the direction of the expectation of the process.

The investment cost of the selected electrical system topology including stand-alone power supply sources is also an important criterion for decision.

The topology of the electrical system of the new refinery is designed as shown in Fig. 2.5 with the idea that the operation continuity will be at the highest level, taking the above examples and investment cost into consideration.

As shown in Fig. 2.5, the power generation and main distribution buses are separate and the electrical system of the new Refinery is connected to the national grid with 154 kV dual transmission lines from one side and to the existing Refinery electrical system from the other side.

Thus, a very important system has emerged between the two refineries and the national grid for energy exchange. A significant advantage of this connection is that there is no possibility of the new Refinery operation being interrupted due to failures or interruptions in each of the three different sources.

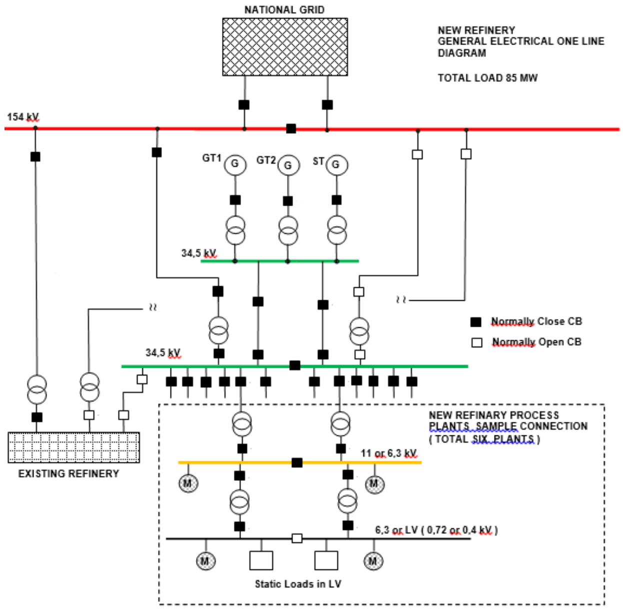


Fig. 2.5

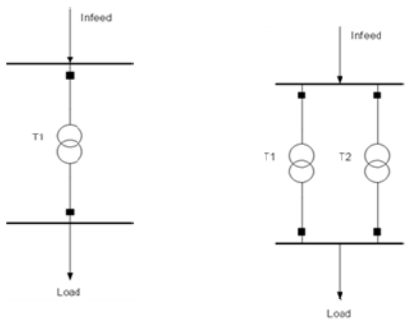
The voltage level of each bus-bar shown in Fig. 2.5 is determined by taking into account both local and international standards, except for low voltage.

The main distribution voltage is selected 34.5 kV due to long distance between the main distribution center and the substations. The motors and generators over 2,0 MW are rated at 11 kV and motors between 400 kW and 2,0 MW are rated at 6,3 kV for reducing voltage drop during motor starting and normal operation.

In order to take into service medium voltage motors reaching up to 10 MW without excessive voltage drops and limiting fluctuations in the electrical system during Refinery island operation, in other words with stand-alone generators, motors are designed for maximum 3.5In starting current. In this way, significant savings have been achieved in investment costs of transformers, generators, conductors, etc. by reducing their sizes.

2.2.1. Power supply security of selected electrical System

The power supply reliability and short circuit levels are basically defined by the network structure. As shown in Fig. 2.6.a, the power supply is provided through by one transformer/cable. Any transformer/cable fault results in immediate interruption of power supply. The load is not supplied after switching off the faulty equipment. However, the structure shown in Fig. 2.6.b has higher availability to supply load in case of any one transformer/cable failures. The remaining transformer/cable handles the complete load. This principle is called N-1 criterion. The week point of this solution is a bus bar failures at any of the load or power source sides.



(a) (b)

Fig. 2.6 Load fed by one transformer compared to a parallel infeed.

In Fig. 2.6.b is used for more than one single load feeder, there are two possibility of bus bar connection. The power supply is done via either a normally closed coupler or a normally open coupler, which can be equipped with an ATS (Automatic Transfer System). In Fig. 2.7, Two separate transformer/cable feeders feed two separate bus bar systems. In case of failure occurred at one transformer, protection devices in upper and lower sides of the failed transformer trip. If fast voltage recovery is required, the ATS should be considered. In case of tripping of lower side circuit breaker, left and right hand sides bus bars are coupled by circuit breaker (bus tie) immediately [8, 9].

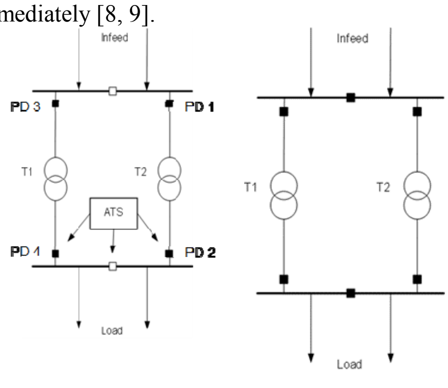


Fig. 2.7 Automatic transfer switch versus a normally closed coupler**.**

The normally closed bus tie configuration represents a better solution from the power supply point of view [8]. The left and right hand side bus bar systems are coupled. Transformer/cable failures and power supply side bus bar failures can be fully compensated. The disadvantage of the connection diagram is the increased short circuit current in case of fault at the load, bus bars or outgoing feeders.

In the case of an interruption of the power supply on the electrical system, all loads, including the motors will be turned off no matter how fast the automatic transfer works.

Therefore, according to the nature of the process, significant economic losses will come into play due to short and long interruptions.

For this reason, although the short circuit current level and the cost of the installation are high, a system has been designed so that the "bus-tie" of all medium voltage systems will be closed for the sustainability of the operation.

2.2.2. Power Supply Security of Selected Power Generation Unit

It has also been noted that the generators that meet the new Refinery's electrical energy demand have to be connected to the electrical system at a level where their operation is easy and sustainable.

In the event of a power interruption in the national grid, the power plant generation capacity has been selected so that generation capacity shall meet refinery’s total electrical energy demand. Two options has been evaluated.

Completely separate power generation plant (Fig. 2.5) connected to the new refinery’s electrical system through transformers [2, 5, 6, 7] or lumped generators separated on medium voltage bus bars (Fig. 2.3) next to the load centers. Advantages and disadvantages of each power generation supply type are summarized as below;

Separate power generation plant;

Advantages:

- Short connection to the national grid and existing refinery electrical system,
- It is not necessary to connect power unit one by one to the medium voltage bus bar,
- Short circuit currents at MV motor load centers are lower,
- Higher efficiency,
- More economical equipment provision and cheaper power generation,
- Availability of higher capacity steam generation from gas turbines exhaust,
- Easy power and steam generation control due to centralized generation sources,
- Opportunity to configure combined cycle power plant operation.

Disadvantages:

- Reactive power is lost over the different voltage levels,
  i. Reactive power compensation is necessary,
  ii. Electrical losses over the voltage levels,
- No reactive power/voltage support at selected MV motor load centers.

Lumped generators at separated voltage levels/bus bars

Advantages:

- Improved voltage stability,
- Less reactive power losses,

Disadvantages:

- Short circuit currents at medium voltage bus bars are higher,
- Long cable connection of generators to MV bus bars.

Due to higher power availability, continuity and more economical reasons, as shown in Fig. 2.5, the separate combined cycle power generation plant has been selected due to the following opportunities and characteristics ;

- Two gas turbines with a capacity of each around 40 MW and one steam generator with a capacity around 40 MW in order to meet the complete New Refinery load in island mode (Independent Power Plant, IPP) operation.
- With the selected configuration, It is also possible to control excess power to export either to national grid or the existing refinery.
- The selected configuration give opportunity to support large amount of steam demand of new refinery under ecological constraints.

3. Simulation Results of Selected Configuration

The following analyzes have been carried out for the energy reliability and continuity of the new refinery electricity system shown in Fig. 2.5.

3.1. Load Flow Analysis

Load flow simulation is made with regards to the selected configuration shown in Fig. 2.5 during both normal and contingency conditions [5]. This is done for normally closed couplers of all medium voltage switchgears and MCCs while all bus bars are fed by only one transformer. In that scenario, the energized MV/MV transformers with the on load tap changers have to be able to maintain the voltage at its bus bar in a range that the voltage at downstream bus bars connected via off load tap changers can be maintained within the standard limits for different operative conditions. The calculated voltages at all bus bars are in the range of 100% -102,5%Un which are permissible limits in accordance with system performance. The calculation has also been repeated for N-1 case which is island operation. In that operation mode, all on load tap changers adept in way that the voltage can be maintained at 99,5% - 102,6%Un. The adaptation can be realized by changing tap positions maximum. The calculated results show that the voltages for normally closed couplers and N-1 operation mode are also in a permissible range.

Therefore, normal operation of the new Refinery power system requires to have OLTC at the main transformers of each substation and 154/34,5 kV main transformers in service, and OCTC (off circuit tap changers) for the rest of transformers.

3.2. Short Circuit Current Analysis

In order to check selected electrical system components' withstand capacity, maximum short circuit current study, to set relay parameters for protection of electrical system and equipment, minimum short circuit current study has been performed [5].

To avoid any problems in the future due to new power sources additions and extensions, all electrical equipment including transformers, SWGs, MCCs, cables etc. has been selected in the highest capacity in the market available.

The calculated maximum short-circuit currents of the new refinery electrical system shown in Fig. 2.5 is given in Table 3.1 for different faults together with relevant bus-bar withstand capacities.

Table 3.1. Calculated Short circuit currents for the power plant parallel operation with national grid and existing Refinery through 154 kV lines

Bus			3-Phase Fault (kA)		
kV	I_{cm} (kA)	I_{cw} (kA)	I''_k	i_p	I_k
154	79	31,5	10,83	29,82	10,41
34,5	100	40	29.45	75,98	20,43
11	100	40	32,14	82,21	21,67
6,3	100	40	27,72	69,83	20,92
0,69	176	80	51,45	124,44	41,03
0,38	176	80	58,61	144,27	54,00

Icm : Rated short circuit making capacity (maximum prospective peak current)
Icw : Rated short-time withstand current for 3 seconds (1 second for LV MCC)

As can be seen from the tablet that the calculated maximum three-phase short-circuit current in any bus-bar does not exceed the short-circuit withstand capacity of the relevant bar. Although not shown in this study, the minimum short circuit current values are also calculated to determine the relay set values.

3.3. Transient Stability Study

In order to perform the overall assessment of the new refinery electrical power system stability strength, a set of severe calculations were simulated [10] taking into account its interconnection with External power grid, island mode and with the existing refinery interconnection.

To achieve this goal a “general case classification” was established as follows.

- Perturbations over new refinery electrical power system and external power grid only (existing refinery electrical system disconnected)
- Perturbations over new refinery electrical power system, external power grid and existing refinery electrical systems interconnected.

Based on the new Refinery electrical power system shown in Fig. 2.5, relevant main cases mentioned above has been studied and results are summarized on a Table. 3.2

4. Conclusion

In order to ensure continuous and safe operation of the new Refinery process operation together with electrical system to be able to withstand all kinds of faults that may occur, and to respond to transient events, the evaluation of the performed calculation results are summarized as follows.

The load flow analysis results from applicable simulations confirm that the equipment within new refinery scope are correctly sized to fully satisfy design requirements related with voltage profile, thermal ratings and power factor compensation.

The short circuit current analysis results indicated in Table 3.1, which are calculated in accordance with applicable operation modes, confirm that the electrical equipment of new refinery are also correctly sized to fully satisfy design requirements.

Table 3.2. The location and clearing time of short circuits occurred on the new, existing refineries electrical systems and their Extension lines including 154 kV interconnection systems.

	Fault Location	Total fault clearance time Relay pick up + CB clearing time (seconds)	Fault clearance device
Parallel operation of new refinery electrical system (3 generators) with external power network	Three phase short circuit at 154 kV cable	0,17	Fault cleared by relay ANSI 21
	Three phase short circuit at 11 kV generator terminals	0.125	Fault cleared by generator relay ANSI 50
New Refinery island mode (3 generators)	Three phase short circuit at 34,5 kV outgoing feeder	0,13	Fault cleared by relay ANSI 50
	Three phase short circuit at 11 kV motor outgoing feeder	0,31	Fault cleared by motor relay ANSI 50
	Three phase short circuit at 6,3 kV motor bus outgoing feeder	0,3	Fault cleared by motor relay ANSI 50
Parallel operation of new and existing refinery electrical systems (3+5 generators) with external power network	Three phase short circuit at 154 kV cable while two refineries connected through 154 kV lines	0,17	Fault cleared by relay ANSI 21
	Three phase short circuit at 34,5 kV cable which is connected two refineries.	0,125	Fault cleared by relay ANSI 21
Parallel operation of new and existing refinery electrical systems (3+5 generators)	Three phase short circuit at 34,5 kV outgoing feeder	0,13	Fault cleared by relay ANSI 50
	Three phase short circuit at 11 kV G4 generator terminals of existing Refinery	0,125	Fault cleared by generator relay ANSI 50

In addition to the critical studies above, transient stability results summarized on Table 3.2 show that the new refinery electrical power system is capable of maintaining the stability after the nearest circuit breaker clears the faults less the than total fault clearance times given in the same table.

If faults cleared by circuit breakers the time shown in Table 3.2, the highest rated synchronous motors with 10,5 MW capacity connected to 11 kV SWG system are kept their stable conditions after low magnitude electrical and mechanical oscillations are finalized.

As a general conclusion, after the detailed evaluation of the new refinery electrical system, studies show that the selected configuration, the number and size of power sources and the electrical equipment used between sources and loads are adequately sized to maintain the new refinery electrical system operation stable during normal and contingency events.

5. References

[1] Ruiz, F.L.I, Hernandez, N.A., Salazar, C.I. "Modernization of substations electrical in the industry petrochemical in Mexico", Industry Applications Society Annual Meeting (IAS), 2012 IEEE, Las Vegas, NV, USA, 7-11 Oct. 2012, pp. 1-14

[2] Fernandez, Fernandez L. "Upgrading a Large Oil Refinery Electric Power System", 36th IAS Annual Meeting IEEE-IAS Annual Conference. September 2001. Chicago, IL, USA. 30 Sept.-30 Oct., 2001, pp.1165 – 1172

[3] Vafemehr, R., "Design of Electrical Power Supply System in an Oil Refinery", MSc. Thesis, Chalmers University of Technology, Goteborg, Sweden, 2011.

[4] Hale, R.S., "The Supply of Electrical Power for Industrial Establishments from Central Stations". Proceedings of the American Institute of Electrical Engineers, 1910, Volume: 29, Issue: 2, pp.219 - 227.

[5] Kucuk, S., Fernandez, L.F., "Extension of the largest Turkish oil refinery's electrical power system", 4th International Conference on Electrical and Electronic Engineering (ICEEE), April 8-10, 2017, Ankara/Turkey, pp.87 - 90

[6] Gavader, A., Ramakumar, R. "Upgrading the power supply to the Al-Zawea refinery in Libya", IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Sept. 6 -9, 2016, Minneapolis, USA, pp.1-5.

[7] Gavader, A., Ramakumar, R. " A study of the AL-Zawea oil refinery power system in Libya", IEEE Power and Energy Conference at Illinois (PECI), Feb.23 -24, 2017, Illinois, USA, pp.1-5.

[8] Kucuk, S. Sarıhan, M. "Comparison and simulation of Automatic load Transfer of critical industrial electrical systems", 4th International Conference on Electrical and Electronic Engineering (ICEEE), April 8-10, 2017, Ankara/Turkey, pp.170 - 176

[9] Ozansoy, C.,"IEC 61850 Based Parallel Bus Transfer Schema for Industrial Substations", Turkish Journal of Electrical Engineering and Computer Sciences, pp. 4339-4354, 2016,

[10] Cetinkaya, H.B., Kucuk, S. Unaldı, Mustafa, Gokce, B. G. "A case study of a successful industrial microgrid operation" 4th International Conference on Electrical and Electronic Engineering (ICEEE), April 8-10, 2017, Ankara/Turkey, pp.95 - 98