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An Evaluation of the ETRR-2 Electrical Power System Short Circuit Study Using ETAP Software

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ABSTRACT

Today, after more than twenty years of operation, Egypt Second Research Reactor (ETRR-2) electrical power system needs to be re-evaluated to ensure that the system is still adequate for present situation of continuous operation under different circumstances, which may be severe in some instances. In the process of re-evaluation of the ETRR-2 electrical power system, it is very important to calculate the short circuit currents at several locations in the system. For electrical system, it is well known that determination of the short circuit current at different locations of the system is very important for two main reasons: first, selection of the short circuit rating for each equipment or the switchboard and second, selection of the rating and setting for protective devices in the protection scheme. This work presents an analytical short circuit study of the ETRR-2 electrical power system by building its model using Electrical Transient Analysis Program (ETAP) software, which was not available during the ETRR-2 design stage at the time. The built model was tested by comparing its simulation results with the designer calculation that was performed on limited points of the system. The authors take the advantages of this new advanced software to evaluate the system in every point in the system. Based on the results of this study, it is feasible to decide which protective device or equipment that needs upgrading to be adequately rated for the present operating circumstances. Moreover, the verified model can be used in future expansion, replacement and renewal studies.

1. INTRODUCTION

In nuclear installations, the reliability of electricity supply becomes very important because it supplies energy needs to nuclear standard laboratories. Specifically in nuclear reactors, the energy supply to the loads should be stable and the quality of electrical power must be maintained. To assure this, many electrical studies should be performed to evaluate the system during the plant design phase. One of these analytical studies is the short-circuit study. These short circuit analyses are important for re-evaluation of the protection system and to prevent or isolate disturbances that may occur [1, 2, 3]. The benefit from the short circuit analysis will be recognized when we need to determine the latest rating value of CB switchgear, overcurrent protection, bus bar protection equipment ,etc., for the benefit of the reliability of components and electrical power supply protection systems. The importance of evaluating the short circuit analysis comes from its use to determine the protection power system settings to protect the system from potential interference from any external and internal faults [4, 5]. Reviewed literatures have demonstrated this [6], where an interactive power system analysis and design tool, is discussed. A previous study [7] deals with the simulation of 220/132 kV substation fault current calculation. The analysis is carried out using advance software Electrical Transient Analyzer Program (ETAP) with detailed short circuit analysis. K. Handono et al. [8] used the ETAP software also to study the electric power supply system of a nuclear power plant. It consists of the main electrical power supply and an emergency power supply supplied from a diesel generator. It shows the value of the short circuit current flowing in each system and component which is used to evaluate the rating of low power supply protection systems and prove that the safety margin is still adequate.

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Today, after more than twenty years of operation, Egypt second research reactor (ETRR-2) electrical power system needs to be re-evaluated in order to be sure that the system is still adequate for present situation of continuous operation under different circumstances, which may be severe in some instances. In the process of revaluation of the ETRR2's electrical power system, it is important to calculate the short circuit currents at several locations in the system. Short circuit analysis was carried out throughout the power supply system using ETAP 16.1 IEC standard (50 HZ) software. The justification of the results of the analysis will be obtained by a more reliable electrical system so that it will improve electricity services at the plant. Besides, the power supply system at ETRR-2 provides a backup supply in the form of a generator set as a backup supply if there is a blackout from electrical grid. The backup system carried out using a generator set is currently still designed to meet the needs of the safe shutdown system, instrumentation, and emergency lighting system and important reactor requirements which lead to safe shutdown.

2. Short circuit calculation methodology

Giving the sizing of an electrical installation and the required equipment, as well as determining the means required for the protection of life and property, short-circuit currents should be calculated for every point in the system. Electrical installations almost always require protection against short-circuits wherever there is an electrical discontinuity. This most often corresponds to points where there is a change in the conductor cross-section. The short-circuit current must be calculated at each level in the installation in view of determining the characteristics of the equipment required to withstand or break the fault current. Figure (1) shows the procedure for determining the various short circuit currents and the resulting parameters for the different protection devices of a low-voltage installation. The calculation methods for short-circuit currents are laid down by standards such as IEC 60909 [9]. It is intended for radial and meshed low-voltage (LV) and high-voltage (HV) circuits.

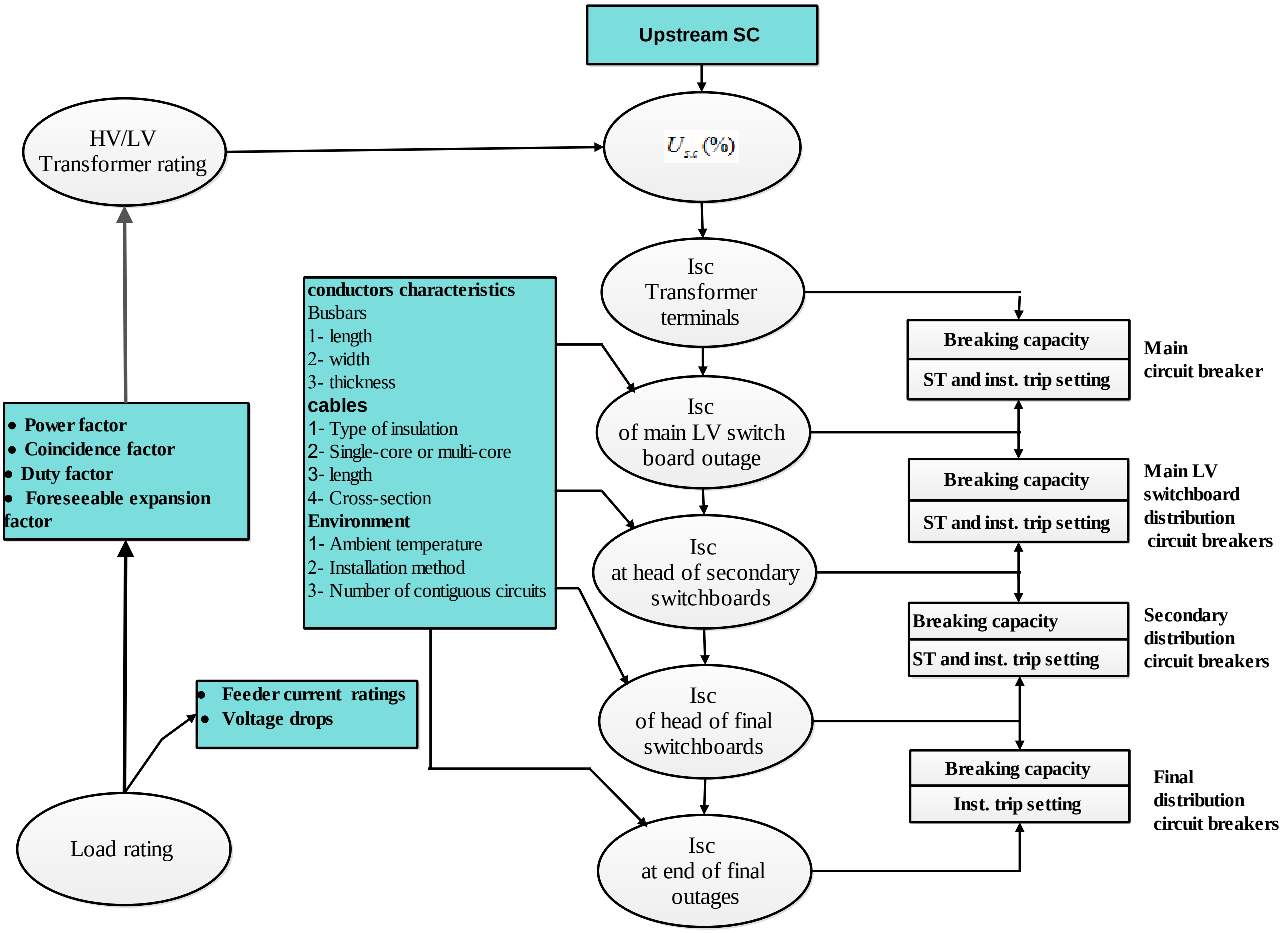

Fig. (1): Short-circuit calculation procedure when designing a low-voltage electrical installation

2.1 Development of the short-circuit current

A simplified network comprises a source of constant AC power, a switch, impedance Zsc that represents all the impedances upstream of the switch, and load impedance Zs(Figure 2). In the real circuit, the impedance source is made up of everything from source of the short circuit including the various networks with different voltages and the series-connected wiring systems with different cross-sectional areas and lengths. In Figure (2), at normal operation without fault, the design current flows through the network [10].

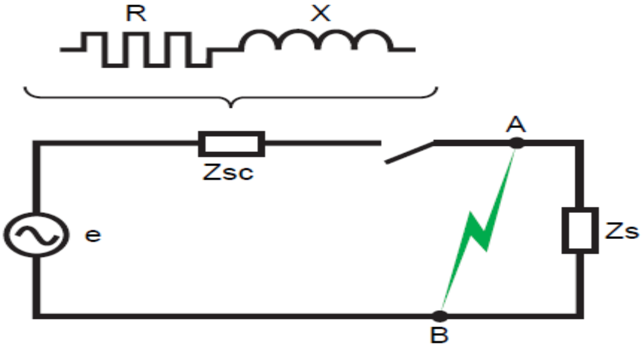

Fig. (2): Simplified network diagram

When a fault occurs between A and B, the impedance between these two points is negligible and this results in a very high short-circuit current (Isc) that is limited only by impedance Zsc. The current (Isc) achieved under transient conditions consist on the reactance's X and the resistances R that create up impedance(Zsc). The short circuit current at the short circuit location A-B is determined using an equivalent voltage source at the short circuit location. The equivalent voltage source at the short-circuit location F is determined by:

$$Veq = c\,Un/\sqrt{3} \qquad \textbf{(1)}$$

Where:

c = voltage factor

Un = nominal system voltage

The voltage factor c depends on the system voltage and it is different for the calculation of minimum and maximum short-circuit currents. It takes following into account [9]:

- influence of loads
- variation of system voltage
- changing of transformer tapings

2.2 Sources of fault current

Short circuit current that flows during a fault coming from running motors and from the electrical utility.

2.2.1 Utility contribution

The contribution from the utility system is the maximum possible three-phase fault duty available at the primary terminals of the transformer and it is equivalent to its symmetrical momentary duty level.

2.2.2 Motor contribution

All connected motor ratings are included as a fault contributing sources, and this contribution is based on the sub transient reactance of the machine. When a short circuit happens, induction motor can make a significant achievement contribution to the system fault current. The bout peak of the fault contribution should be possessed into account for selecting the protective device rating. It is well known that the three-phase short circuit current due to an induction motor can be calculated using the typical model of the induction motor [11, 12, 13]. The instantaneous and time variation short circuit current for the three-phase fault can be obtained using following equations [11].

$$\begin{aligned} i_a = \frac{-U_m}{X"} e^{-1/Ta}\, cos\lambda \\ + \left[U_m \left\langle \frac{1}{X'} - \frac{1}{X} \right\rangle e^{-t/T'} \right. \\ \left. + U_m \left\langle \frac{1}{X"} - \frac{1}{X'} \right\rangle e^{-t/T"} \right] \cos\,(\omega t + \lambda) \qquad \textbf{(2)} \end{aligned}$$

$$\mathrm{X"} = \mathrm{X_r} + \mathrm{X_s} \qquad \textbf{(3)}$$

$$\mathrm{X'} = \mathrm{X_s} + \frac{\mathrm{X_M X_r}}{\mathrm{X_M + X_r}} \qquad \textbf{(4)}$$

$$X = X_s + X_M = \omega(L_M + L_l) \qquad \textbf{(5)}$$

$$\alpha = \frac{r_l \omega}{X} = \frac{1}{T_a} \qquad \textbf{(6)}$$

Where:

U_m = Maximum phase voltage

λ= phase voltage angle at moment of short circuit

$X_s = \omega L_1$= stator reactance

$X_r = \omega L_2$= rotor reactance

f = frequency of voltage supplied to the stator.

r_l= stator resistance

L_1= stator leakage inductance

L_M= magnetizing inductance

$\omega = 2\pi f$

T_a= time constant

For unbalanced faults such as single line to ground faults, line to line faults, or double line to ground faults, there have been no direct empirical equations for time variation short circuit currents. The calculations are normally based on symmetrical component theory with a positive sequence and negative sequence representation of an induction motor model. As a result, it will be useful for performing computer simulations to determine the first peak of short circuit current contribution due to the induction motor. The following sections present recalculation and evaluation of analytical short circuit study of the ETRR-2 electrical power system by building its model using Electrical using (ETAP).

3. ETRR-2 Electrical Power System Description

Egyptian second testing research reactor (ETRR-2) is an open pool type reactor, its thermal power is 22 MW (maximum power), at average thermal flux $8.1*10^{13}$nv and maximum thermal flux $2.7*10^{14}$nv, which uses a plate-type 19.7% enriched uranium with aluminum cladding of fuel. The neutron flux is moderated by light water and reflected by beryllium. The reactor pool houses the core, irradiation grid, cooling system piping, nuclear and conventional instrumentation and some of the reactor irradiation facilities. Control system is used for controlling and shutting down the reactor. ETRR-2 measuring systems are based on three redundant sets of sensors. Alarms fired based on the philosophy of two out of three logics [14-15]. The ETRR-2 electrical system design follows a conventional practice for industrial plants except that extra reliability requirement for the nuclear reactor is provided. The basic structure of the electrical system design is shown in Figure (3). It has been chosen to be a primary selective scheme type in order to provide simple bus arrangement for easy, safety, and flexibility in operation [16]. The electric loads have been classified to the following categories:

Class **"A"** Loads: are those loads fundamental from a safety point of view; they require uninterruptible AC power.

Class "B" Loads: are loads whose reconnection to the system is convenient in order to increase their availability after the interruption of electrical power supply from the external lines.

Class "C" Loads: admit interruptions on the supply for indefinite time.

The ETRR-2 Reactor is fed from the outside by two medium voltages lines (11 KV), L1 and L2 (Class "C" supply). These lines feed two transformers identified as T1 and T2. In normal operation, these transformers feed the Class "C" Right and Left bus bars (Low voltage). Two main groups of loads are connected to the "C" bus bars, the essential ones and the non-essential ones. The essential loads are fed from the essential service switchboard. This switchboard is either fed from the "C" bus bars or from a power plant (the latter in case of loss of the external power supply). In addition, the essential service switchboards feed the uninterruptible power system that constitutes the Class "A" supply and the Class "A" bus bars. If the two classes (Class "C" supply and Class "B" supply) are interrupted, the Uninterruptable Power System (USP) feeds Class "A" loads.

As mentioned previously, there is a diesel power plant that supplies the ETRR-2 reactor (supply Class "B"), in case of simultaneous interruption of the supply by the external lines. This power plant consists of two diesel generators. It is located at an independent area from the reactor building to increase the power security. The UPS which feeds the loads Class "A" is based on long life batteries. Generally, each distribution system has sufficient capacity to supply the required loads under all required conditions of ETRR-2, and withstand the maximum credible over current, under fault and transient conditions, without damage or adverse effects on any of its components.

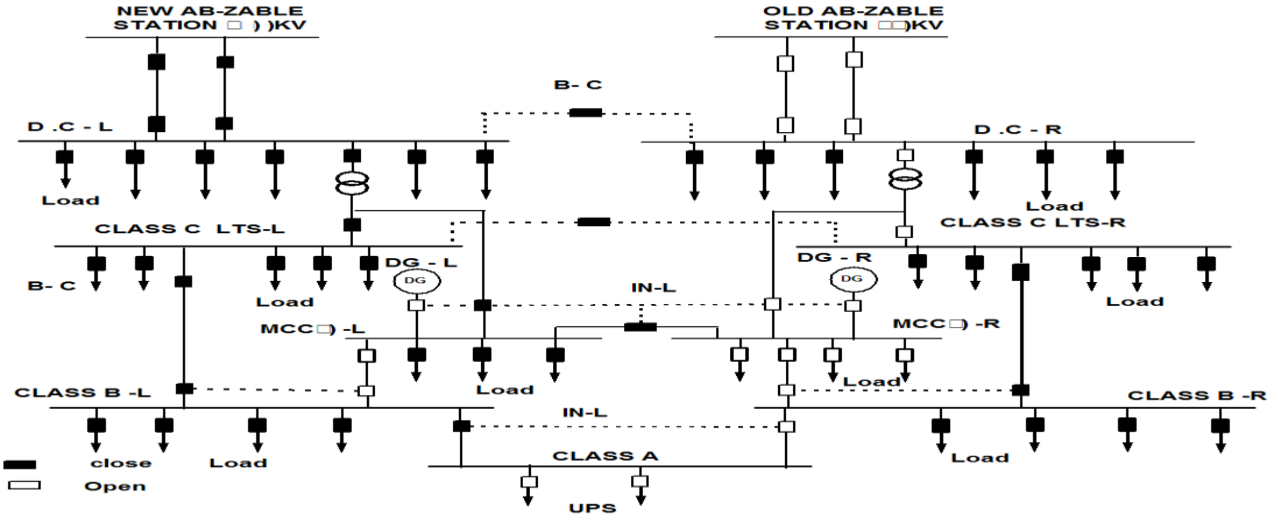

Fig. (3): The basic structure of the electrical system

3.1. Class "C" bus bars

The normal power supply is capable of starting and operating all required loads. Each of the transformers (primary voltage 11 KV, 50 Hz, secondary voltage 0.400/0.231 KV, connection group D y 11) has 100 % of the total sum of individual maximum demands. Tables (1) illustrate the normal power requirements in class C bus bars or low voltage switchboards - left (LTS-L) and right (LTS-R).

3.2. Class "B" bus bars

Distribution System Class "B" supply is provided by two sources, the normal power supply and the emergency diesel generator. The diesel generators are designed to furnish AC power adequate for supplying Class "B" and the uninterruptible power system, in the case that the external lines are unavailable, without automatic selection and synchronization. There is no parallel operation of the diesel generators with the normal power supply neither between the two diesel generators. The connection of power supply from the power plant to ETRR-2 is done manually. The reactor’s electric distribution system supplied by the diesel generators is subdivided into two distribution systems (Class "B" L, and Class "B" R). Each distribution system has sufficient capability to supply its connected loads under all required operation conditions of the electrical system, and withstand the maximum credible overcurrent under fault and transient conditions, without damage or adverse effect on any of its components.

Power is distributed to motors at 380 V, 50 Hz, 3 phases, through combination fused switch-magnetic-motor-starters. As buses Class "B" are capable of receiving power from either of the two supplies (normal supply or from the emergency diesel generator), reliability of power is assured and safety is increased. The emergency diesel generators that feed the ETRR-2 class B loads are 300 KVA each one, with voltage 380/220 V, 50 HZ. Table (2) illustrates the class B load requirements or essential switchboards left (ESB-L) and right (ESB-R).

3.3. Class "A" bus bar

This bus feeds loads which are very important for reactor safety such as instrumentation and control loads. They are fed through a UPS unit which is connected to the ESB busses [14, 15].

Table (1): Class C loads requirements

LTS- L load		LTS- R load	
Equipment Connected	Connected Loads Kw	Equipment Connected	Connected Loads Kw
Primary pump	112.00	Primary Pump	112.00
Primary pump	112.00	Primary pump	112.00
Fan	0.75	Fan	0.75
Fan	0.50	Supervision & Control System	8.00
Stabilized Load	7.00	ESB-R	117.77
ESB-L	116.89	MCC-1	3.10
MCC-5	96.45	MCC-2	12.00
MCC-10	9.40	MCC-6	50.50
MCC-18	14.00	MCC-8	18.65
MCC-19L	10.00	MCC-9	30.00
MCC-21L	708.03	MCC-13	55.90
PLS-1	28.76	MCC-15	5.40
PLS-5	19.64	MCC-16	5.00
PLS-9	20.92	MCC-17	5.00
PLS-13	20.19	MCC-19R	10.00
Control	0.10	MCC-21R	478.48
Subtotal	**1271.63**	MCC-23	4.60
		MCC-26	9.40
		MCC-29	5.00
		PLS-3	25.76
		PLS-7	22.50
		PLS-11	15.13
		PLS-15	14.95
		PLS-17	20.00
		Control	0.10
		Subtotal	**1142.99**

Table (2): Class B loads requirements

ESB - L loads		ESB- R loads	
Equipment Connected	Connected Loads Kw	Equipment Connected	Connected Loads Kw
Pump	15.00	Pump	15.00
Pump	3.00	MCC-3	17.00
Alarm panel	2.00	MCC-7R	21.35
Stabilized Load	3.00	MCC-22R	11.20
MCC-4	7.10	PLS-4	1.60
MCC-7L	19.85	PLS-8	1.85
MCC-22L	11.20	PLS-12	1.00
PLS-2	3.05	PLS-16	12.42
PLS-6	1.54	ESB-T	33.25
PLS-10	1.85	Instrumentation	3.00
PLS-14	12.95	Control voltage	0.10
ESB-T	33.25	**Subtotal**	**117.77**
Instrumentation	3.00		
Control voltage	0.10		
Subtotal	**116.89**		

4. Original short circuit analysis with approximation

Short circuit fault is a disturbance that occurs because of an error between the parts that are caused by the emergence of a voltage which is much greater than the normal current. Short circuit disorders in the system can also be caused based on external and internal causes. One of the very important tasks, when planning and operating power systems, are the short-circuit calculations (SCCs). Faults and short-circuits can be minimized in the system through design, planning, performed maintenance and operation of the system, but cannot be totally avoided.

In the ETRR-2 design stage, a short circuit studies have been done to evaluate the electrical system design. The calculations were made considering the one-line diagram illustrated in Figure (3). Short circuit currents flow during a fault come from the electrical utility and from running motors. Only large motors, specifically motors corresponding to the primary and secondary pumps which are connected to main buses LTS-L/R and MCC21-L/R, have been considered truthfully. To facilitate the calculation process, other small motors have been grouped and considered as one big motor representing them (lumped motor model). Moreover, the calculation was based on the consideration that the short circuit is far-from-generator and is supplied at one point by an electricity supply network. Another main approximation in that short circuit study is neglecting other load points (such as lighting and electric heating loads) [17]. The single line diagram of the electrical system supply with those approximations is shown in Figure (4) which presents all sources of short circuit current and all significant circuit impedances in a worst-case scenario of short circuit study when the left bus bar (LTS-L) is heavily loaded. In this situation:

- All the loads are in operation
- The working two primary pumps are connected to the LTS-L switchboard
- The working two secondary pumps are connected to the MCC21-L switchboard.
- Only one transformer (the left one) feeds all the plant loads.

Recently, The calculation of this situation was repeated again using modern and well known tool available now (ETAP ver. 16.1 IEC standard (50 HZ) software). Figure (5) shows the model which has been built to simulate the SC case studies in the original calculations. To validate the model, the obtained results have been compared with the results of the original calculations. Table (3) shows a comparison between the two results and it appeared that errors are within tolerances. Of course, this simplified model with that approximation is not accurate since SC calculations are affected by accurate motor models as well as the actual impedances of operating loads in the system [18].

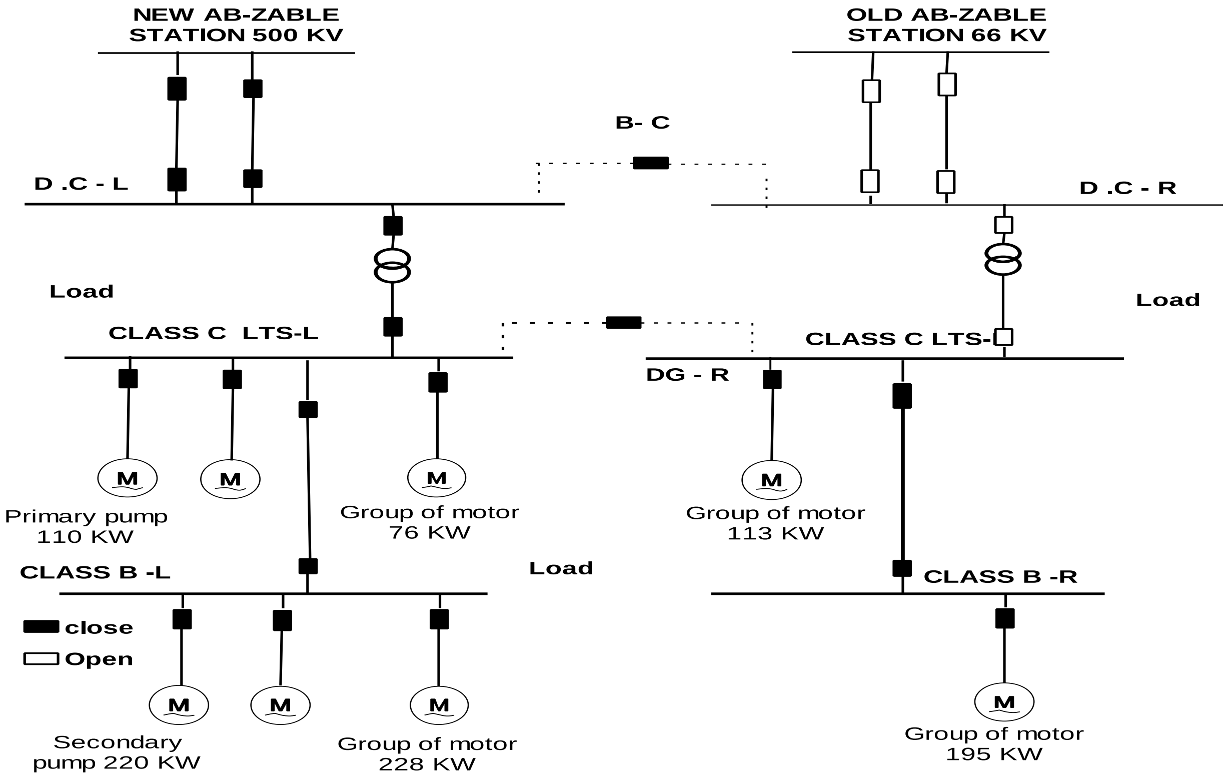

Fig. (4): Single line diagram in a worst case scenario of short circuit study when the left bus bar (LTS-L) is heavily loaded

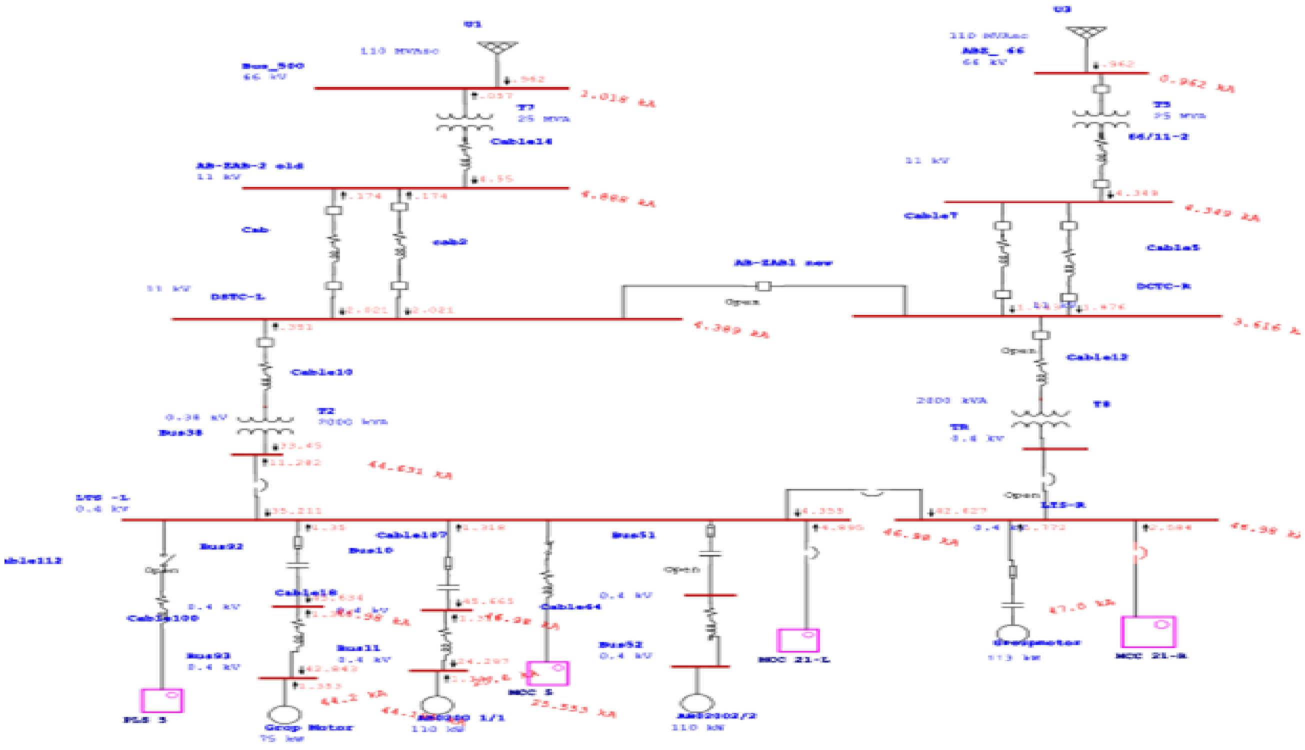

Fig. (5): ETAP model in the case of figure 4 (with approximations)

Table (3): Comparison between the original study results and the results obtained from ETAP model (with approximations)

Bus bar	Ref values KA	ETAP values KA	% Error
D.C – L	4	4	0
D.C – R	4	4	0
LTS-L	46.97	46.9	0.15
LTS-R	46.97	46.9	0.15
MCC-21-L	44.94	44.5	0.98
MCC -21-R	44.6	44.2	0.89

5. Short circuit analysis with real and detailed data

Protection settings, coordination and dimensioning of switchgear require accurate and detailed short-circuit studies. This is, firstly, because switches and breakers have to be designed to switch off short-circuits in a safe way and in short time. Secondly, switchgears have to be designed to withstand any SC current that could happen in its buses [11].

In this section, after evaluating the model, the short circuit currents in ETRR-2 electrical system were analyzed using real input data and the new tools that are available now to perform the study more accurately with all the details required. Now we have the opportunity to present all the loads even the small ones. Moreover, the short circuit value can be obtained at any bus in the system wherever it is. The entire plant circuit parameters are updated in the ETAP model with correct impedances and real loading simulation in order to get more accurate results. Figure (6) shows the detailed ETAP model without approximations in a worst-case scenario of short circuit study when the left bus bar (LTS-L) is heavily loaded. Applying the study on the same worst case scenario, the following results given in Tables (4 & 5) were obtained. By analyzing the obtained results of the simulation study which shows the value of the short circuit current flowing in each bus and component and using it in the re-evaluation of the electrical power system, it is found that the existing components ratings and protection devices ratings and settings is still suitable and the safety margin is achieved and far above the real short circuit currents.

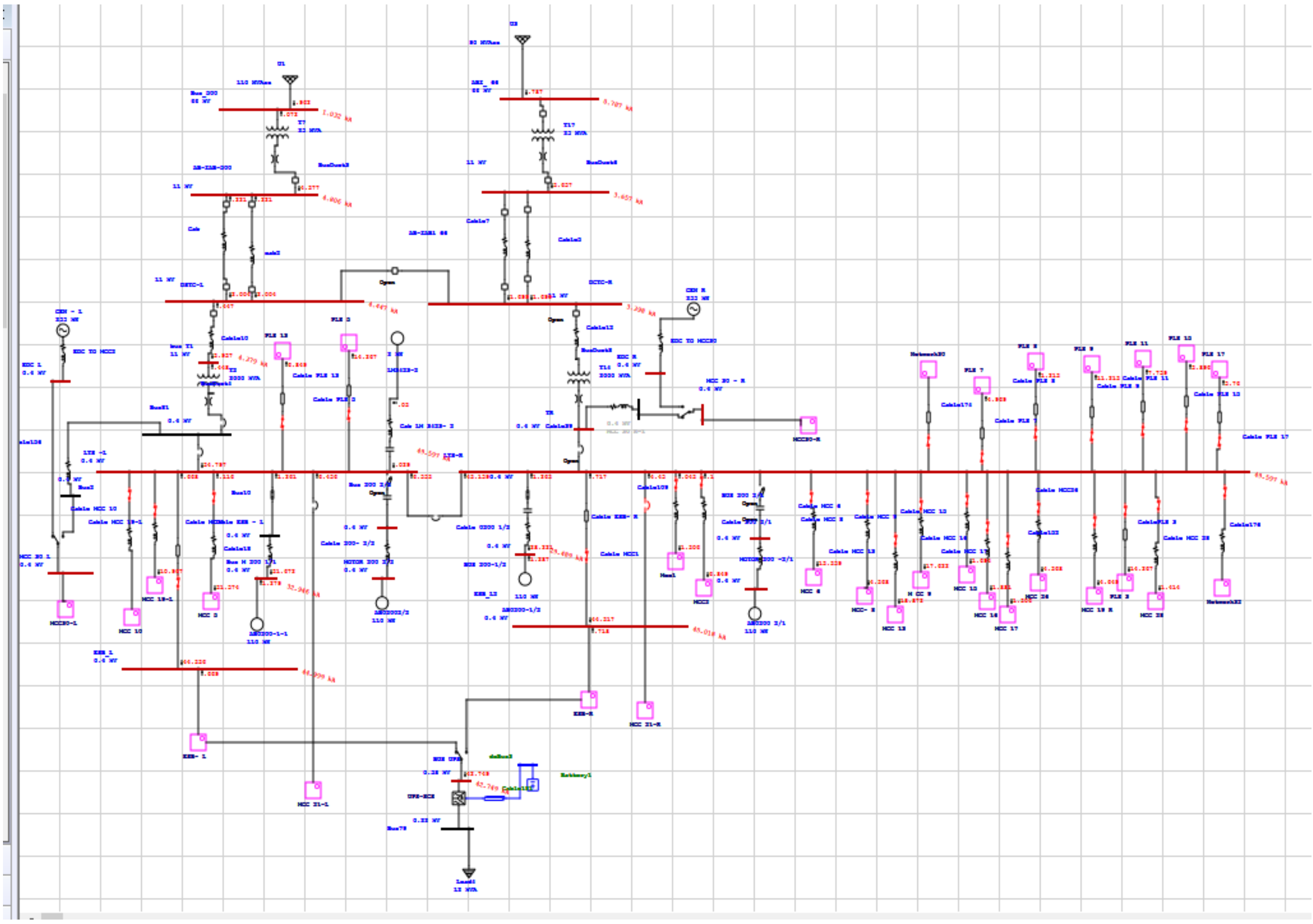

Fig. (6): Detailed ETAP model in a worst-case scenario of short circuit study when the left bus bar (LTS-L) is heavily loaded (without approximations)

Table (4): Short circuit values obtained from the ETAP study (without approximations) Buses connected to LTS-L and ESB-L and LTS- R &ESB R

LTS- L & ESB -L			**LTS- R &ESB-R**		
Equipment Connected	SC RMS KA	SC Pack values KA	Equipment Connected	SC RMS KA	SC Pack values KA
DIC CENTER - L	4.44	10.87377	DIC CENTER - R	4.44	10.87377
LTS -L	49.1	120.2483	LTS- R	49.1	120.2483
AB02001/1	32.9	72.00201	AB02001/2	29.4	72.00201
ESB-L	44.9	109.9623	ESB-R	44.9	109.9623
MCC-5	30	3.257234	MCC-1	1.33	3.257234
MCC-10	1.2	16.89843	MCC-2	6.9	16.89843
MCC-18	1.2	32.57234	MCC-6	13.3	32.57234
MCC-19 L	10.9	10.67785	MCC-8	4.36	10.67785
MCC-21 L	46.58	42.9563	MCC-9	17.54	42.9563
PLS-1	13.5	45.99312	MCC-13	18.78	45.99312
PLS-5	14.14	4.114401	MCC-15	1.68	4.114401
PLS-9	11.17	4.60421	MCC-16	1.88	4.60421
PLS-13	6.8	3.183762	MCC-17	1.3	3.183762
AB03001/1	8.8	11.26562	MCC-19R	4.6	11.26562
AB0 400	1.2	109.4724	MCC-21R	44.7	109.4724
MCC-4	2.4	3.183762	MCC-23	1.3	3.183762
MCC-7L	5.8	10.53091	MCC-26	4.3	10.53091
MCC-22L	3.26	6.857334	MCC-29	2.8	6.857334
PLS-2	2.1	34.53158	PLS-3	14.1	34.53158
PLS-6	9.8	12.14728	PLS-7	4.96	12.14728
PLS-10	2.1	18.93114	PLS-11	7.73	18.93114
PLS-14	6.7	9.502306	PLS-15	3.88	9.502306
			PLS-15	3.88	9.502306
			PLS-17	5.74	14.05754
			AB300-1/2	12.6	30.858
			MCC-3	6.74	16.50658
			MCC-7R	5.9	14.44938
			MCC-22R	3.16	7.738992
			PLS-4	2	4.898096
			PLS-8	1.2	2.938858
			PLS-12	2	4.898096
			PLS-16	3.84	9.404344

6. CONCLUSION AND DISCUSSION

This paper describes the electrical power system of ETRR-2 and gives information about the nature of its electrical loads. Those loads have been classified into different classes according to their importance to safety. Then, the study presents the original SC analysis that has been done in the design stage of the reactor. It was carried out using simplification of the electrical system for the worst case of operation of the electrical system where all the loads are in operation and the left bus bars are heavily loaded with maximum loads. This simplified test system was modeled again in ETAP with the same worst-case scenario selected in the design stage. The results obtained from this model have been compared with the original SC study results in order to make validation to the built model. After that, the entire plant circuit parameters are updated in this ETAP model with real and detailed motors data, corrected impedances and real loading simulation. Applying the study on the same worst-case scenario, more accurate results were obtained. The new short circuit study has shown that the difference between the original study results and the new one is not so effective and it will not lead to any change of the design parameters that were applied in the design stage where safety margins are still adequate. Neither of the short circuit level rating for equipment and switchboards nor the rating and setting for each protective device in the protection scheme needs to be changed. Now, after building a model for the ETRR-2 electrical system, this verified model can be used in future expansion, replacement and renewal studies.

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