JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

POWER SYSTEM ANALYSIS OF AN INDUSTRIAL ELECTRICAL NETWORK

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ABSTRACT

The Tamil Nadu Electricity and Light (TEAL) industry is supplied with 11 kV voltage from TANGEDCO, with a 2.5 MVA distribution transformer and two panels for energized loads. A load flow, short circuit, and motor starting study were conducted using the Electrical Transient Analyzer Program (ETAP) platform. The load flow study found that the voltage profile at all buses is within the limit. Short circuit analysis was conducted using symmetrical and unsymmetrical faults, indicating that the available circuit breaker rating is sufficient. The highest capacity motor was identified as a 30 HP motor, drawing a large starting current from the supply during startup. A static motor starting study was conducted using the Institute of Electrical and Electronics Engineers (IEEE) 399–1997, IEEE 3002.7–2018 standards to check voltage dip at buses during motor startup. The voltage at other buses was also within the limit. Overall, the industry's voltage profile and motor starting are within the required limits.

Keywords— Load flow analysis, short circuit analysis, motor starting study, ETAP, power system analysis and industrial electrical network.

I. INTRODUCTION

Studies of power systems are essential to the effective and secure functioning of industrial electrical networks. Under both regular and emergency circumstances, they calculate losses, voltage levels, and actual and reactive power flows. Short circuit studies determine the fault current magnitudes for the selection of protective equipment, whereas motor starting studies evaluate system reactivity and voltage dips during motor starts. Medium Voltage Panels 1 and 2 and a distribution transformer with a 2.5 MVA rating are linked to the industry's 11 kV voltage supply from TANGEDCO. Three diesel-rated generators are employed in the event of a power outage, and connections are established via subterranean cables.

Objective:

The study aims to analyze load flow, short circuit, and motor acceleration to determine circuit loadings, power flows, and system losses in the electrical network. It also conducts a motor acceleration study to design appropriate circuit breakers and switchgear.

II. LITERATURE SURVEY

2.1 Institute of Electrical and Electronics Engineers (IEEE) 3002-2018 IEEE [1].

This standard provides guidelines for conducting motor starting and load flow analysis in industrial and commercial power systems, outlining the appropriate conditions for motor acceleration studies.

2.2 Z. L. Wu et al. [2] focus on the application of ETAP in power distribution systems, specifically in protection coordination and load flow studies.

ETAP facilitates efficient coordination of protection devices, enabling fault isolation and load flow analysis for safe and optimal operation of power distribution networks under various operating conditions.

2.3 A. K. Gupta et al. [3] examine the use of ETAP for evaluating short-circuit currents and protection settings in power systems.

The study demonstrates ETAP's ability to calculate fault currents in short-circuit conditions, ensuring protection devices are set correctly to isolate faults quickly and prevent equipment damage.

III. PROPOSED STUDY

1. Automation Industry and Loads

The automation industry receives 11 kV voltage from TANGEDCO, connected to a 2.5 MVA rating distribution transformer and Medium Voltage Panels 1 and 2. The industry has a panel board for secure connection, underground cables for transformer and load switchgears, and three generators with diesel power. Two 365 kVAr capacitor banks and automatic tap changers for transformers are also in place.

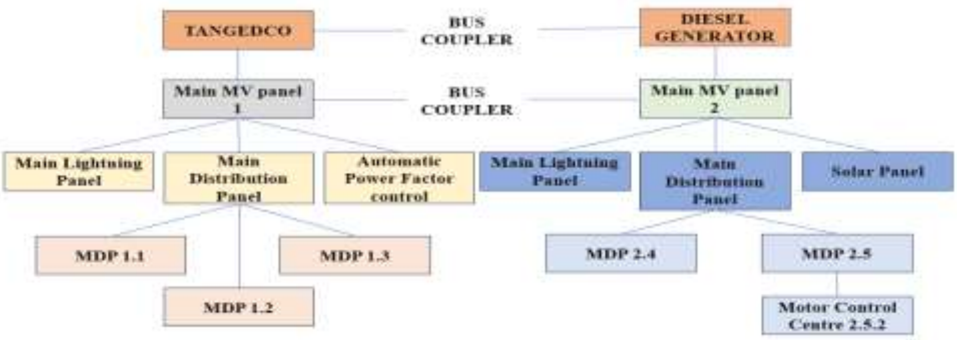

Figure 1 Representation of Automation industry

The panel board has 11 outgoing switchgears connected to various loads in the industry. These loads include MVP-1 connected loads like Automatic Power Factor Control (APFC), non-A/C shop floor, non-destructive testing panel, fire hydrant panel, UPS panel-1, and canteen UPS room panel, and MVP-2 connected loads like A/C shop floor, air compressor, chiller panel, UPS panel-2, and APFC - 2.2.

2. Load Flow Study

This study examines various aspects of a power system, including component loadings, steady-state voltage levels, reactive power flow, transformer tap settings, losses, generator exciters/regulators' voltage set points, and system performance during emergency situations. It also considers losses within the system.

Standard

IEEE Std 3002.2-2018 is recommended for performing LFA and analysing power systems in industrial and commercial settings.

3. Short Circuit Study

The Short Time Rating (STR) is a crucial tool for assessing the capabilities of various equipment, including transformers, cables, transmission lines, generators, motors, switchgear, current transformers, and circuit breakers, as well as determining the voltage increase during a fault and evaluating existing system components' resistance to potential short circuits.

Standard

International Electro technical Commission (IEC) 60909-2016: This standard includes various sections for different types of short circuit analyses, as outlined in Table 1.

Table 1 Different parts in IEC 60909

IEC 60909		
SHORT CIRCUIT CURRENTS IN THREE-PHASE A.C. SYSTEMS		
IEC STANDARD	PARTS	TITLE
IEC 60909-0	PART-0	Calculation of currents
IEC 60909-1	PART-1	Factors for the calculation of short-circuit currents according to IEC 60909-0
IEC 60909-2	PART-2	Data of electrical equipment for short-circuit current calculations
IEC 60909-3	PART-3	Currents during two separate simultaneous line-to-earth short circuits and partial short-circuit currents flowing through earth
IEC 60909-4	PART-4	Examples for the calculation of short-circuit currents

Assumptions Of IEC 60909-0-2016

During a short circuit, fault type remains constant, network configuration remains unchanged. Opening a bus coupler to protect a coupled bus reduces system impedance, increasing fault current. Arc resistances are ignored, treating faults as bolted faults, which is not possible.

4. Motor Starting Study

Modelling Techniques

ETAP software employs static and dynamic starting techniques for motor acceleration studies, focusing on conceptual redesign, unavailable dynamic characteristics, and voltage effects on buses, low-voltage motors, and generator-powered systems.

Standard

IEEE 3002.7-2018 – IEEE recommended practice for conducting motor starting studies and analysis of industrial and commercial power systems.

Voltage Dips During Motor Starting

Starting large motors in a facility can cause a significant voltage drop, slowing down other motors, potentially leading to stalling and cascading voltage drops. This can also reduce motor lifespan, negatively impact electronic devices and control equipment, and cause lighting flicker.

Table 2 Voltage levels for the system during motor start-up.

Voltage drop location or problem	Minimum allowable voltage (% rated)
System voltage	95 % to 105 %
At terminals of starting motor	80%
All terminals of other motors that must reaccelerate	70%
Ac contactor pick-up (by standard)	85%
DC contactor pick-up (by standard)	80%
Contactor hold-in (average of those in use)	60% to 70%
Solid-state control devices	90%

IV.SIMULATIONS

ETAP created a digital electrical system model, incorporating feeders, switchgear, motors, and control panels, and conducted sensitivity analyses to understand voltage and motor loading variations.

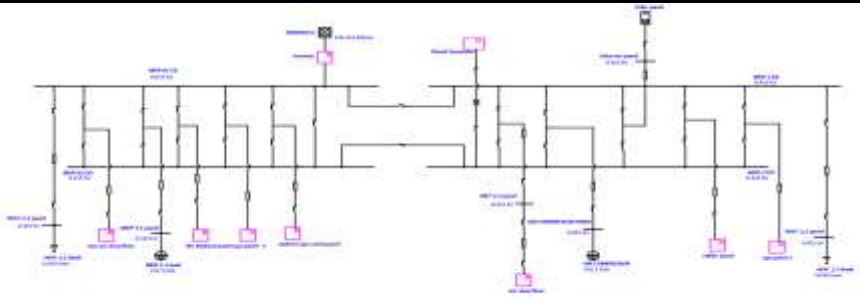

Figure 2 ETAP layout of the system.

1. Simulation of Load Flow Study

The load flow study is conducted under 7 scenarios and the real and reactive power results are obtained for both the incoming side and the load side (canteen UPS room panel).

Table 2 Real and reactive power flow at incoming side

SCENERIO	BUS VOLTAGE IN kV	kW	kVAr
Normal condition	11	274.9	1639
Maximum grid voltage, Minimum load	11.55	635.9	3790
Minimum grid voltage, Maximum load	10.45	53	315.7
Grid outage	11	0	0
DG outage	11	1875	983.7
Bus outage	11	0	0
Future load	11	274.9	1639

Table 3 Real and reactive power flow at Canteen UPS room panel

SCENERIO	BUS VOLTAGE IN kV	kW	kVAr
Normal condition	0.404	70.4	43.5
Maximum grid voltage, Minimum load	0.412	70.4	43.5
Minimum grid voltage, Maximum load	0.409	35.1	21.7
Grid outage	0.409	70.4	43.5
DG outage	0.408	70.4	43.5
Bus outage	0.409	70.4	43.5
Future load	0.405	95.7	59.1

2. Simulation of Short Circuit Study

A detailed power house model is created, and a short circuit study is conducted, analyzing symmetrical and unsymmetrical faults.

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Table 4 Symmetrical fault current and the circuit breaker selection

Table 5 Unsymmetrical (L-L-G) fault current and the circuit breaker selection

Table 6 Unsymmetrical (L-G) fault current and the circuit breaker selection

S. No.	Bus name	Three phase symmetrical fault current(kA)	Switch gear Fault rating Ik" (kA)	Replacement of circuit breaker needed?
1	HT VCB panel	26.072	55	NO
2	APFC – 1.1	17.212	25	NO
3	Non – A/C shop floor	10.068	25	NO
4	Non – Destructive Testing Panel	11.276	25	NO
5	Fire Hydrant Panel	13.459	25	NO
6	UPS panel – 1	12.084	25	NO
7	Canteen UPS room panel	16.184	25	NO
8	A/C shop floor	10.443	25	NO
9	Air compressor	16.858	25	NO
10	Chiller panel	10.886	25	NO
11	UPS panel - 2	17.183	25	NO
12	APFC – 2.2	17.212	25	NO

S. No.	Bus name	Unsymmetrical fault current(kA)	Switch gear Fault rating Ik" (kA)	Replacement of circuit breaker needed?
1	HT VCB panel	25.09	55	NO
2	APFC – 1.1	8.895	25	NO
3	Non – A/C shop floor	4.520	25	NO
4	Non – Destructive Testing Panel	5.569	25	NO
5	Fire Hydrant Panel	4.518	25	NO
6	UPS panel – 1	4.082	25	NO
7	Canteen UPS room panel	7.707	25	NO
8	A/C shop floor	5.256	25	NO
9	Air compressor	7.829	25	NO
10	Chiller panel	5.446	25	NO
11	UPS panel - 2	12.944	25	NO
12	APFC – 2.2	9.456	25	NO

S. No.	Bus name	Unsymmetrical fault current(kA)	Switch gear Fault rating Ik" (kA)	Replacement of circuit breaker needed?
1	HT VCB panel	25.632	55	NO
2	APFC – 1.1	16.718	25	NO
3	Non – A/C shop floor	10.503	25	NO
4	Non – Destructive Testing Panel	13.334	25	NO
5	Fire Hydrant Panel	12.121	25	NO
6	UPS panel – 1	14.449	25	NO
7	Canteen UPS room panel	10.44	25	NO
8	A/C shop floor	12.094	25	NO
9	Air compressor	10.056	25	NO
10	Chiller panel	10.718	25	NO
11	UPS panel - 2	17.174	25	NO
12	APFC – 2.2	18.744	25	NO

Table 4 shows symmetrical fault current values recorded during a three-phase symmetrical fault in ETAP, with all fault currents falling within acceptable limits. The circuit breaker rating is adequate to handle the fault current, but only for a short duration. Table 5 shows unsymmetrical fault current values, with all fault currents remaining within permissible limits. The circuit breaker rating is sufficient to withstand the fault current, preventing the need for load replacement.

3. Simulation of Motor Starting Study

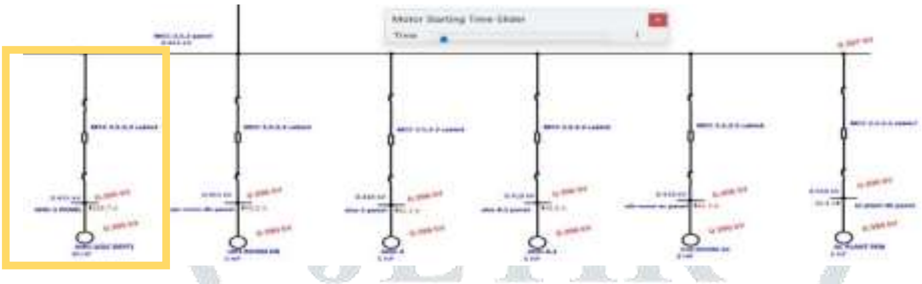

Figure 3 Detailed view of bus with 30 HP motor.

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Table 7 Starting current values for different time intervals in the motor starting of 30 HP motor.

Table 8 Details of the bus voltages during the high-capacity motor starting.

Sl.no	Time (sec)	Starting Current (A)	Bus voltage(kV)
1	0	0	0.411
2	0.5	0	0.411
3	1	223.7	0.395
4	2	223.7	0.395
5	3	223.7	0.395
6	4	39.8	0.409
7	5	39.8	0.409
8	6	39.8	0.409
9	7	39.8	0.409
10	8	39.8	0.409

S. No.	BUS NAME	Bus voltages (kV		
		t = 0 sec	t = 3 s	t = 8 s
1	HT VCB panel	0.415	0.411	0.414
2	APFC – 1.1	0.413	0.399	0.412
3	Non – A/C shop floor	0.412	0.387	0.411
4	Non – Destructive Testing Panel	0.412	0.384	0.411
5	Fire Hydrant Panel	0.411	0.358	0.399
6	UPS panel – 1	0.414	0.4	0.413
7	Canteen UPS room panel	0.415	0.388	0.414
8	A/C shop floor	0.408	0.382	0.407
9	Air compressor	0.412	0.386	0.411
10	Chiller panel	0.409	0.355	0.4
11	UPS panel - 2	0.414	0.4	0.412
12	APFC – 2.2	0.412	0.385	0.411

The switchgear rating can handle up to 25 kA, but the fault current tends to 223.7 A, within permissible limits. The highest capacity motor starts at 223.7 A, requiring no switchgear replacement. The 30 HP motor's starting current is 5 times greater than the rated current, indicating successful starting based on voltage at the motor terminal and switchgear level.

The table 8 displays the details of voltage dip at other buses due to the highest motor start up. It is observed that at the time of motor start up the voltage at other buses dips to 0.355 kV which is not within the limit. So the other buses experience voltage dip.

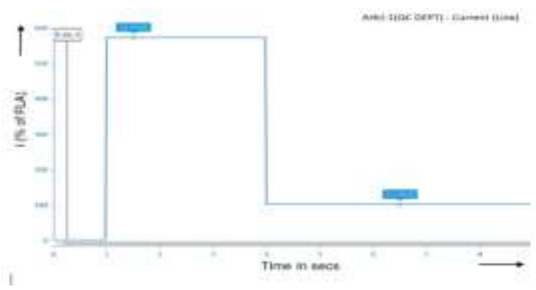

Figure 4 I - Time graph of 30 HP motor

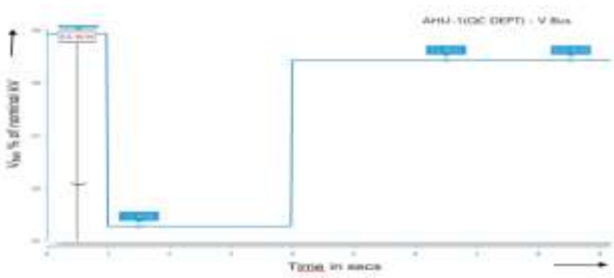

Figure 5 V_{bus} - Time graph of 30 HP motor

V. CONCLUSION

This study conducted a comprehensive power system analysis for the automation industry, evaluating circuit loadings, real and reactive power flows, and system losses. Short circuit studies identified potential risks to equipment, such as circuit breakers and transformers, under fault conditions. Motor starting studies highlighted potential challenges like voltage fluctuations, impacting other loads and causing operational issues like motor stalling and equipment damage.

FUTURE SCOPE

A detailed model of circuit breakers and switchgears can be developed for load relay coordination, ensuring timely protection and tripping of electrical equipment in power system network faults.

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