

# Dynamic Motor Starting and Harmonic Analysis for a Chemical Manufacturing Industry

Jeevananthan J<sup>1</sup>, Dr. V. Prasanna Moorthy<sup>2</sup>

PG Student, Power Electronics and Drives, Government College of Technology, Coimbatore, India – 641013<sup>1</sup>

Professor/EEE, Government College of Technology, Coimbatore, India – 641013<sup>2</sup>

**Abstract:** For manufacturing industries like chemical manufacturing industries, maintaining a stable and continuous power supply is very important because power quality issues can affect continuous industrial processes. Starting large motors can lead to voltage dips and usage of non-linear loads can lead to power quality issues. Hence, in this project, motor starting and harmonic analysis are carried out for the chemical industry using ETAP under various operating scenarios. As a result, it checks whether the voltage dip during motor starting and the THD at the PCC.

**Keywords:** Voltage dip, Motor Acceleration, Harmonics, Power quality issues.

## I. INTRODUCTION

Industrial power systems in chemical manufacturing industries contains several large motors, transformers, variable speed drives and critical loads that requires a stable power supply for continuous operations. Large motors while starting intakes high inrush current, which can lead to voltage dip and affect other loads connected to the system and reduces the motor performance. In addition, non-linear loads present in the network generate harmonics that may lead to overheating, power quality issues and reduces equipment life. To address these issues, this project involves the analysis of motor starting and harmonics for an industrial distribution system under different operating scenarios such transformer outage, feeder outage, opening of circuit breakers, tie connections and addition of loads to study how the system behaves during power outages, normal operating condition and maintenance.

The study aims to:

- To check whether the voltage dip during motor starting is within the limit.
- To examine whether the motor can able to start.
- To check the THD at the point of common coupling.

## II. SYSTEM DETAILS

The industrial facility receives electrical power from two independent 115/11.5 kV substations with a combined system capacity of 49 MW. These substations provide an 11.5 kV supply to the main medium-voltage buses namely M1A, M1B, M2A, and M2B. From these buses, electrical power is distributed to various process sections identified as Unit 1 through Unit 8, as illustrated in Figure 1. Among them, Unit 8 represents the recently added expansion section of the plant. The bus arrangement is designed in such a way that each bus can receive power from either substation through interconnecting tie breakers.

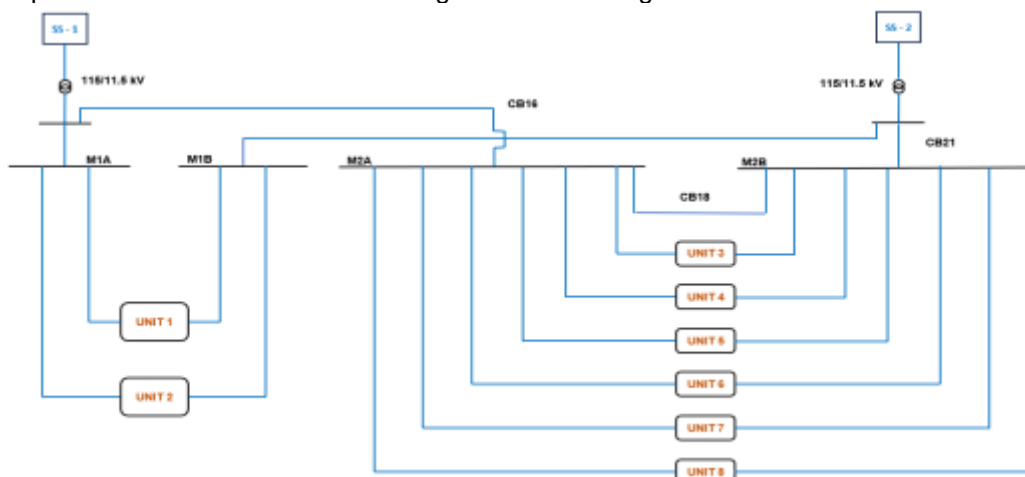


Fig. 1. Block diagram of the overall system

In Unit-8, the electrical distribution network is designed with an 11.5 kV medium-voltage switchgear system identified as MV-1, which is connected through two separate incoming feeders extended from the existing 12 kV switchgear arrangement. The received medium-voltage supply is converted into lower voltage levels using dedicated step-down transformers consisting of two 11/0.69 kV transformers and two 11/0.4 kV transformers. High-voltage motors operating at 11 kV are connected directly to the MV-1 switchgear, while the low-voltage loads are distributed through separate LV switchgear sections, where the 690 V loads are connected to LV-1 and the 400 V loads are connected to LV-2.

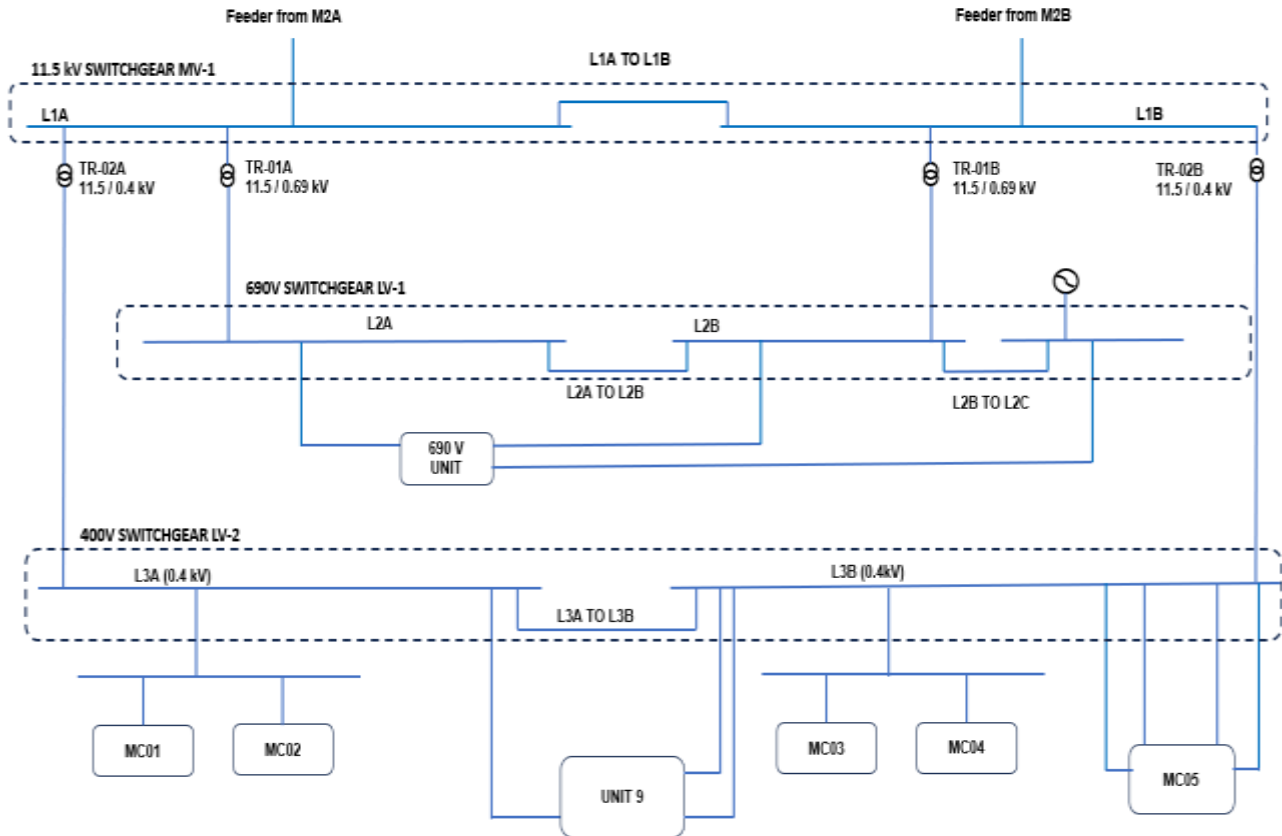


Fig. 2. Block diagram of Unit-8

**III. MOTOR ACCELERATION STUDY**

When large motors are started, it will take high inrush current to develop the initial torque, due to this voltage dip happens in the system, this voltage dip may also affect other individual loads connected to the system. The study evaluates whether the motor can able to start or not and whether the voltage dip during motor starting is within the acceptable limit as per the standard IEEE 3002.7.

TABLE I ALLOWABLE VOLTAGE LIMIT AS PER STANDARD

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. HARMONIC ANALYSIS

When non-linear equipment such as variable speed drives, rectifiers, inverters and power electronic devices are used they draw non-sinusoidal current from the supply, this results in harmonic generation. These harmonics affect the quality of electrical power and may create problems such as overheating of equipment, increased power losses, malfunction of protective devices, voltage distortion, and reduced efficiency of motors and transformers. The study helps to check whether the THD at the PCC is within the limit as per IEEE 519.

TABLE II VOLTAGE DISTORTION LIMIT

Bus voltage V at PCC	Individual harmonic (%) $h \leq 50$	Total Harmonic distortion THD (%)
$V \leq 1.0$ kV	5	8
$1$ kV $< V \leq 69$ kV	3	5
$69$ kV $< V \leq 161$ kV	1.5	2.5
$161$ kV $< V$	1	1.5 <sup>a</sup>

#### V. OPERATING SCENARIOS

Different operating scenarios are analyzed to evaluate the performance, reliability, and stability of the power system under varying load and network conditions. These scenarios help in identifying the system behaviour during normal operation, peak demand, equipment outage, and fault conditions. By studying multiple operating cases, the system can be designed to maintain voltage stability, reduce power losses, improve protection coordination, and ensure continuous power supply to critical loads. The analysis also helps in verifying the adequacy of transformers, generators, cables, and protective devices under different loading patterns and contingency situations. Such studies are essential for enhancing system security, operational flexibility, and overall power quality in industrial and commercial power systems.

##### A. SCENARIO-1

In this case, the electrical supply arrangement is configured such that Unit-8 operates using a single incoming source from SS-1. This is achieved by keeping breakers CB-L1A and CB-L1A TO L1B in service condition, while isolating CB-L1B. For the 690 V distribution system, only transformer TR-01A is utilized to energize all bus sections. Breaker CB-L2A is maintained in the ON position, whereas CB-L2B and CB-L2C are disconnected. The power is then distributed across the switchgear through the bus-coupler connections established by closing tie breakers CB-L2A TO L2B and CB-L2B TO L2C.

##### B. SCENARIO-2

In this operating condition, Unit-8 receives power exclusively from substation SS-2 through the feeder connected to M2B. This configuration is established by keeping breakers CB-L1B and CB-L1A TO L1B in the closed position while breaker CB-L1A remains isolated. For the 690 V switchgear arrangement, transformer TR-01A acts as the only power source. Breaker CB-L2A is maintained closed, whereas breakers CB-L2B and CB-L2C are kept open. The supply is extended to all bus sections through the tie connections formed by closing breakers CB-L2A TO L2B and CB-L2B TO L2C.

##### C. SCENARIO-3

Under this system configuration, the power supply to Unit-8 is provided solely from substation SS-2 through the M2B feeder path. This operating condition is achieved by maintaining breakers CB-L1B and CB-L1A TO L1B in the closed state while keeping CB-L1A disconnected. In the 690 V switchgear network, breakers CB-L2A and CB-L2C remain energized, whereas CB-L2B and CB-L2B TO L2C are isolated. Consequently, transformer TR-01A alone supplies the switchgear system, and the bus sections are interconnected through the closed tie breaker CB-L2A TO L2B.

#### VI. RESULTS AND DISCUSSION

##### A. RESULTS OF LOAD FLOW ANALYSIS

The Load flow analysis is carried out using ETAP and the results are tabulated below. During motor starting the bus voltage drops beyond the permissible limit. To bring it to acceptable limit the transformers TR-01A and TR-01B are set at -2.5% tap setting and transformers TR-02A and TR-02B are set at -5% tap setting.

TABLE III RESULTS OF LOAD FLOW ANALYSIS FOR SCENARIO-1

Bus ID	Bus Rated Voltage (kV)	Result Bus Voltage (kV)	Result Bus Voltage (%)	Remarks
L1A	11	10.8	98.18	Within limit
L1B	11	10.8	98.18	Within limit
L2A	0.69	0.7	101.45	Within limit
L2B	0.69	0.684	99.13	Within limit
L2C	0.69	0.7	101.45	Within limit
LP-1	0.4	0.402	100.5	Within limit
EMC-1	0.4	0.412	103	Within limit
L3A	0.4	0.402	100.5	Within limit
L3B	0.4	0.386	96.5	Within limit
DB-11	0.4	0.386	96.5	Within limit
DB-21	0.4	0.39	97.5	Within limit
MC01	0.4	0.4	100	Within limit
MC02	0.4	0.411	102.75	Within limit
DS-1	0.4	0.388	97	Within limit
MC03	0.4	0.4	100	Within limit
MC04	0.4	0.4	100	Within limit

TABLE IV RESULTS OF LOAD FLOW ANALYSIS FOR SCENARIO-2

Bus ID	Bus Rated Voltage (kV)	Result Bus Voltage (kV)	Result Bus Voltage (%)	Remarks
L1A	11	10.5	95.45	Within limit
L1B	11	10.5	95.45	Within limit
L2A	0.69	0.67	97.1	Within limit
L2B	0.69	0.689	99.86	Within limit
L2C	0.69	0.661	95.8	Within limit
LP-1	0.4	0.392	98	Within limit
EMC-1	0.4	0.392	98	Within limit
L3A	0.4	0.396	99	Within limit
L3B	0.4	0.39	97.5	Within limit
DB-11	0.4	0.388	97	Within limit
DB-21	0.4	0.386	96.5	Within limit
MC01	0.4	0.386	96.5	Within limit
MC02	0.4	0.389	97.25	Within limit
DS-1	0.4	0.4	100	Within limit
MC03	0.4	0.386	96.5	Within limit
MC04	0.4	0.39	97.5	Within limit

TABLE V RESULTS OF LOAD FLOW ANALYSIS FOR SCENARIO-3

Bus ID	Bus Rated Voltage (kV)	Result Bus Voltage (kV)	Result Bus Voltage (%)	Remarks
L1A	11	10.78	98	Within limit
L1B	11	10.78	98	Within limit
L2A	0.69	0.67	97.1	Within limit
L2B	0.69	0.677	98.12	Within limit
L2C	0.69	0.677	98.12	Within limit
LP-1	0.4	0.386	96.5	Within limit
EMC-1	0.4	0.388	97	Within limit
L3A	0.4	0.389	97.25	Within limit
L3B	0.4	0.396	99	Within limit
DB-11	0.4	0.384	96	Within limit
DB-21	0.4	0.383	95.75	Within limit

MC01	0.4	0.386	96.5	Within limit
MC02	0.4	0.388	97	Within limit
DS-1	0.4	0.392	98	Within limit
MC03	0.4	0.383	95.75	Within limit
MC04	0.4	0.383	95.75	Within limit

The results from the table III, IV and V shows that the voltage drop in all buses are within the acceptable limit of  $\pm 5\%$  from the nominal value. Hence the system operates with the stable operating limits.

### B. RESULTS OF MOTOR STARTING ANALYSIS

The motor starting analysis is executed in ETAP and the results are tabulated below. The scenario-3 with future load is considered as worst case as it has more number of loads. So the voltage dip high, hence considering this scenario for motor starting analysis can allow as to check, whether the voltage dip exceeds the permissible level. The motors are divided into priorities based on their time of start.

TABLE VI RESULT AT TIME = 0s

TIME (sec)	BUS	RATED VOLTAGE (kV)	ACTUAL VOLTAGE (kV)	% VOLTAGE	REMARKS
Before Starting (Time = 0s)	L1A / L1B	11	10.7	97.27	Within limit
	L2A / L2B / L2C	0.69	0.68	98.55	Within limit
	L3A	0.4	0.388	97	Within limit
	L3B	0.4	0.4	100	Within limit

TABLE VII RESULT AT TIME = 1s

TIME (sec)	BUS	RATED VOLTAGE (kV)	ACTUAL VOLTAGE (kV)	% VOLTAGE	REMARKS
Before Starting (Time = 1s)	L1A / L1B	11	10.8	98.18	Within limit
	L2A / L2B / L2C	0.69	0.66	95.65	Within limit
	L3A	0.4	0.38	95	Within limit
	L3B	0.4	0.385	96.25	Within limit

TABLE VIII RESULT AT TIME = 5s

TIME (sec)	BUS	RATED VOLTAGE (kV)	ACTUAL VOLTAGE (kV)	% VOLTAGE	REMARKS
Before Starting (Time = 5s)	L1A / L1B	11	10	90.91	Within limit
	L2A / L2B / L2C	0.69	0.62	89.86	Within limit
	L3A	0.4	0.38	95	Within limit
	L3B	0.4	0.36	90	Within limit

TABLE IX RESULT AT TIME = 15s

TIME (sec)	BUS	RATED VOLTAGE (kV)	ACTUAL VOLTAGE (kV)	% VOLTAGE	REMARKS
Before Starting	L1A / L1B	11	10.3	93.64	Within limit
	L2A / L2B / L2C	0.69	0.63	91.3	Within limit

(Time = 15s)	L3A	0.4	0.37	92.5	Within limit
	L3B	0.4	0.358	89.5	Within limit

TABLE X RESULT AT TIME = 25s

TIME (sec)	BUS	RATED VOLTAGE (kV)	ACTUAL VOLTAGE (kV)	% VOLTAGE	REMARKS
Before Starting (Time = 25s)	L1A / L1B	11	10.56	96	Within limit
	L2A / L2B / L2C	0.69	0.63	91.3	Within limit
	L3A	0.4	0.378	94.5	Within limit
	L3B	0.4	0.362	90.5	Within limit

The results from the tables VI, VII, VIII, XI and X shows that the voltage dip while starting large motors remains within the limit, after increasing the tap of transformers TR-01A and TR-01B to -2.5% tap setting and transformers TR-02A and TR-02B to -5% tap setting.

### C. RESULTS OF HARMONIC ANALYSIS

The Harmonics analysis is performed using ETAP software and the results are tabulated below.

TABLE XI RESULTS OF HARMONIC ANALYSIS FOR SCENARIO-3

S.No	Bus Name	Bus Rated Voltage (kV)	THDV%	As per IEEE-519	Status
1	L1A	11	2.5	< 5	Within limit
2	L1B	11	2.46	< 5	Within limit
3	L2A	0.69	2	< 8	Within limit
4	L2B	0.69	2.01	< 8	Within limit
5	L2C	0.69	2.06	< 8	Within limit
6	MC01	0.4	1.66	< 8	Within limit
7	L3A	0.4	2.22	< 8	Within limit
8	L3B	0.4	2.89	< 8	Within limit
9	MC02	0.4	3.5	< 8	Within limit
10	MC05	0.4	4.5	< 8	Within limit
11	MC03/04	0.4	4.66	< 8	Within limit

The results from the table XI shows that the harmonic at each buses are within the acceptable limit as per IEEE 519.

## VII. CONCLUSION

The motor starting and harmonic analysis of the industrial power distribution system was carried out successfully using ETAP under different operating scenarios. The motor starting study was performed to evaluate the effect of large motor starting currents on the electrical network. From the analysis, it was observed that the motors accelerated properly without causing unacceptable voltage drops or instability in the system. The bus voltages remained within acceptable operating limits during all considered operating conditions, which confirms the reliability of the power distribution network during motor starting conditions.

The harmonic analysis was conducted to study the effect of non-linear loads such as variable speed drives and power electronic equipment on the system. Parameters including voltage distortion, current distortion, and Total Harmonic Distortion (THD) were evaluated and compared with the limits specified in IEEE 519. The results showed that the harmonic levels were within permissible limits and the overall power quality of the system was maintained satisfactorily. The study also highlighted the importance of interconnected feeders, tie-breaker arrangements, and backup supply systems in improving system reliability and ensuring continuous industrial operation.

**REFERENCES**

- [1]. Institute of Electrical and Electronics Engineers (IEEE), IEEE Std 399-1997 – IEEE Recommended practice for Industrial and Commercial Power Systems Analysis, IEEE Standards Board approved 16 September 1997, pp 165-206.
- [2]. Institute of Electrical and Electronics Engineers (IEEE 3002.2-2018) standards Recommended Practice for conducting load-flow studies of Industrial and Commercial Power Systems which provide guidelines for load flow studies in industrial and commercial power systems.
- [3]. Dr. Aung Zaw Latt, April 2019, “Three Phase Induction Motor Starting Analysis Using ETAP”, IJLTEMAS, Vol. VIII, Issue IV.
- [4]. Bhavik R Prajapati, et al., April – 2018, “Motor Starting Analysis Using ETAP Software”, “2<sup>nd</sup> International Conference on Current Research Trends in Engineering and Technology”, Vol. 4, Issue 5, pp.816-820.
- [5]. Safa Ahmed Younis and Omar Muwaffaq Mahmood Alyousif, March – 2022, “Electrical Power System Harmonics Elimination Using ETAP”, Al-Rafidain Engineering Journal (AREJ), Vol. 27, Issue 1, pp. 99–109.
- [6]. A. Y. M. Abbas, et al., 2020, “Optimal PV Penetration for Power Losses Subject to Transient Stability and Harmonics”, Procedia Computer Science, Vol. 175, pp. 508–516, using ETAP 19.5 for harmonic and stability analysis.