Analysis and design of a grid connected real plant in Libya using ETAP software

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Summary
Grid analysis is the most important part in electrical power engineering assessment aiming to evaluate the grid stability state. We have drawn innovatively Almajd Factory, A real plant installed in Libya, after part site and grid measurements collection, giving us the possibility to design our integrated and complex plant connected to the utility grid. Mainly, the power source transformers, high voltage circuit brakers, cables, load profiles and the equivalent model of the existing factory elements integrating inductive elements and inner loads. This research article focuses especially on detailing its design and presenting several analyses in steady state and transient aspects at once. Various numerical computations of this large integrated power system with optimal computing speed, including an overall grid state like power flow which explicates active and reactive power, Harmonic distortion and motors start up based upon real recorded measurements obtained from the site sensors. The whole model has been implemented and validated using ETAP in order to analyze the grid state in the off-line mode. The obtained statistical report highlights the design effectiveness and the trustworthiness of the modeling which presents our background of decision making.

Key words:
Load Flow Analysis, Motor Start Up analysis, THD rate, Real plant.

1. Introduction

From this section, input the body of your manuscript according to the constitution that you had. For detailed information for authors, please refer to [1]

The development of new paradigms to emulate fully functional factory components and evaluate its real time dynamic interaction for either inter or intra compartments based on off-line mode is a crucial issue for enterprises decision making and healing of some problem origin affecting optimal working conditions. Thus, it appears as a good reason to attempt a highly effective and reliable design for analysis and understanding origins of some drawbacks. Unyielding background of reliable data for modeling purpose is very important to find out cutoffs and non optimal use causing additional energy losses to act based on them.

Modeling and simulation is identified as the major means toward factories advancement well known as industries 4.0 revolution [1-4]. Load Flow Analysis (LFA), Harmonic distortion (THD) and Start up motor analysis are the fundamental calculations in the examination of the distribution systems. In this same axis:

The Authors in [5] introduce a LFA with the help of ETAP in order to choose the electrical equipment parameters based on output results in which LFA correspond to design and planning basics. They discuss required input for modeling of electrical system in accordance with standards and withstand worst case conditions and cases.

While authors in [6] gave a classification of Load Flow equations (LFE), Different buses types and the most used methods to solve LFE problems and their performance comparison. Newton-Raphson method results undertake the overall grid components including generators, transmission lines and load equivalent profiles.

In [7] authors present a comparison about the most used numerical methods. Analysis performed in Matlab testing IEEE 9, 30, 57-Bus grid. Methods used are Gauss-Seidel, Newton-Raphson and Fast Decoupled .The simulation results were assessed in term of number of iteration, tolerance value, convergence speed and computational time. They conclude that Newton-Raphson is the most reliable method.

Authors in [8] proposed a new load flow method for either radial or weakly meshed distribution systems besides evaluating the load models impacts. For the case of weakly meshed distribution systems, number of loops impacts is analyzed and at the end a comparison of radial and weakly meshed grids is done. Computation's time, voltage profile, number of iterations and total power losses are the main topics of their studies using MATLAB on IEEE 33, 69bus.

The second important analysis is harmonic load flow. Distortion caused by non linearity of voltage versus current and introductions of high frequencies which causes the harmful phenomenon of resonance.

A relatively fast and accurate approach for harmonic analyses using decoupled technique is proposed by authors in [9]. The last cited approach aimed to resolve nonlinear loads and implicitly voltage distortions passive filters are then used to minimize the distortion respecting IEEE 519 Standard on 123-bus IEEE grid.

Bus parameters and transmission line are determined moreover load flow of active and reactive power is

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presented in [10] for the case of 132kV EHV network using ETAP software.[11] Presents a probabilistic load-flow solution for large scale radial distribution systems based on Monte Carlo technique to predict grid state. It is assumed that the uncertainties of bus loads and generation can be estimated or measured.

In addition a forward/backward sweep approach is performed as a deterministic load flow solution to reduce the overall required algorithm time on IEEE 33-69node grids with MATLAB software.

Our last challenge is the requirement for investigating startup analysis of Induction motor transient study. It is manifested on Induction motors starting current and related voltage flickers.In [12], Authors focused with the aid of ETAP software on a 132KV grid detailed analysis performing load flow, harmonic distortion and transient motor start up.

A summarize of commonly used methods for the right selection of starting devices is presented in [13]. They prove that starting current and time could be reduced and voltage profile stability could be improved thanks to capacitor installed at the motor buses.

In this article, the main novelty resides on modeling of a real and compound system composed by the grid and a newly installed plant in Libya. This last manifest some issues in term of cutoffs caused by abnormal functionality. We propose to track down its origin further the grid state in term of newly updated grid code respect in transient and steady state regime at once. Real measurements are performed and integrated on ETAP model for improvement of control purpose. For this end several analysis tools are used to describe the real state of the under study system.

This paper is divided into three main sections. Section II introduces the description and modeling. In section III System Analysis is performed on ETAP and results are commented. The last section presents obviously the results and proposed measures to be taken.

2. DESCRIPTION AND MODELING

2.1 One line grid diagram study case

In which there is two depart lines of 220 kV tied to the power transformers. Each one has 63 MVA rating power and its relative function is to transform voltage level from 220KV to 30KV where there is the 30 KV common bus and representing the medium grid voltage plan. Two profile loads are connected at 30KV representing both residential and industrial cases. Inclusive load modeling is performed on ETAP based upon real grid measurement.The system configuration is shown in Fig. 1.

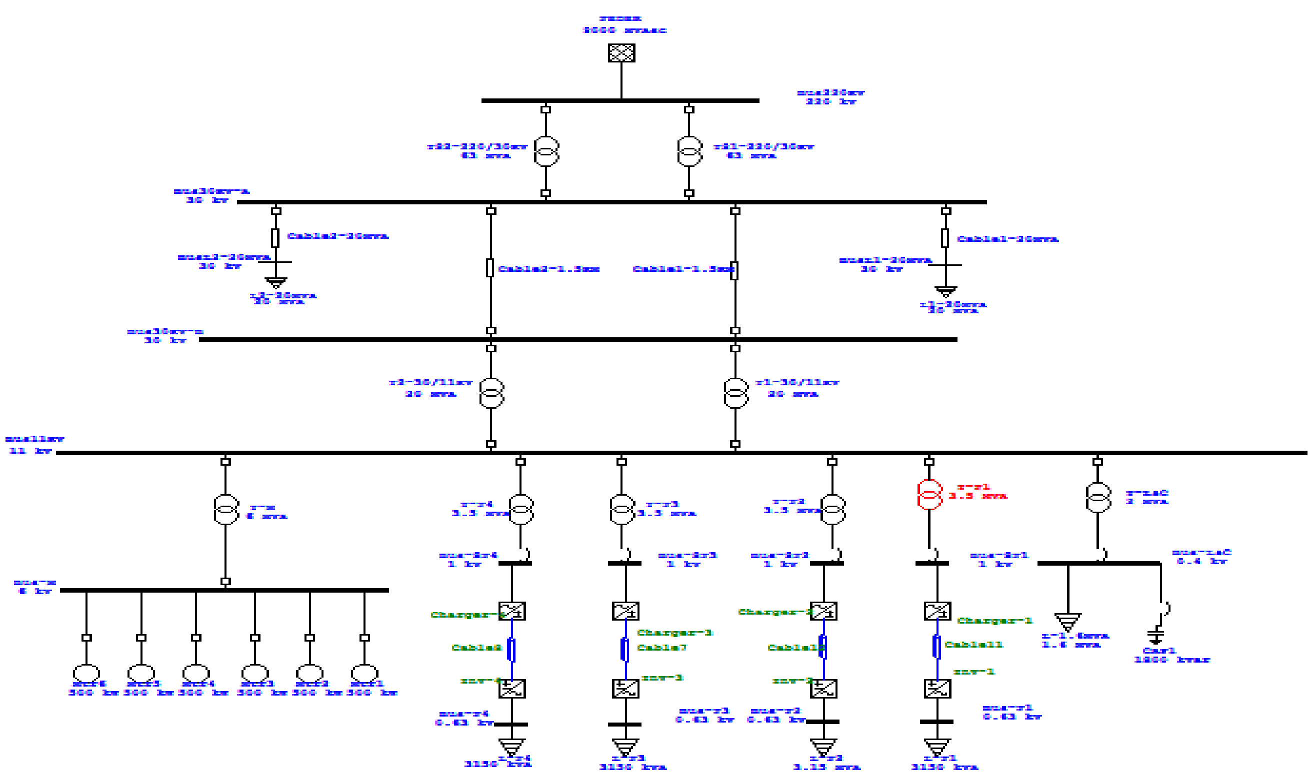

Fig. 1 One line diagram Grid

The single line diagram incorporates measure points and buses names shown on the same figure to facilitate their nomenclature. The overall grid is sub divided into sections according to real site state in order to emulate its behavior for analyses and monitoring purpose.

2.2 Modeling of the transformers ts1&ts2

Fig. 2 is a scoop of Fig. 1 showing two 220 kV incoming lines from the 220kV power source feeding the transformers.

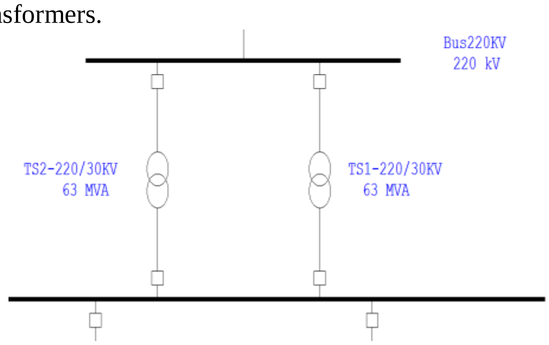

Fig. 2 Simulated diagram of 220/30kV transformers using ETAP

They step down the voltage from 220KV to 30KV where there are two load profiles connected at this level shown on details in Fig.3.

2.3 Modeling of medium voltage connected loads

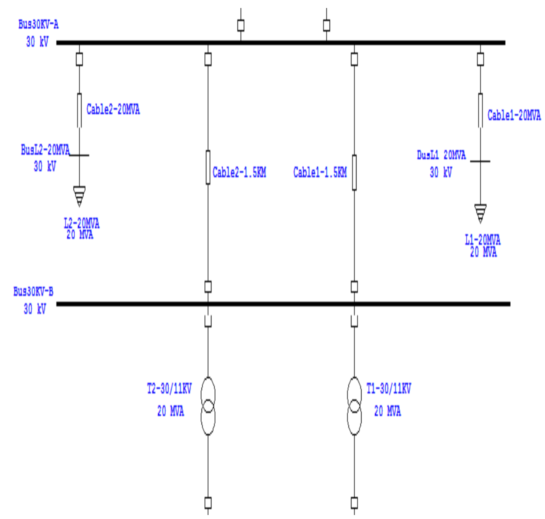

Fig. 3 Simulated diagram of 30KV plan

All cables length, loads values and transformer characteristic are shown on Figure.3 respecting the reality of things. Transformers 30/11KV connect the common plant bus to the medium grid.

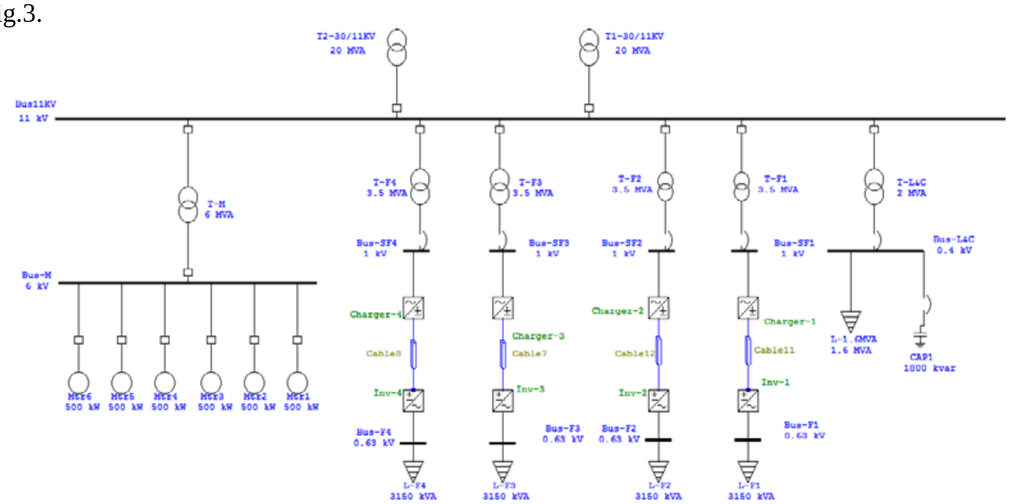

Fig. 4 Modeling view of Almajd Factory at 11KV on ETAP

2.4 Modeling of Almajd Factory at 11KV

The plant modeling includes the common bus 11KV which is the point of coupling to the grid. Several transformers step down the voltage toward feeding inner factory loads. There are active loads like motors or static loads. Load needs are guaranteed as using electronic power devices like inverters and converters when needed.

3. System Analysis on ETAP

3.1 Optimal load Flow Analysis

Accordantly to the ground reality, Loads are modeled taking into consideration static loads. Table.1 shows the implemented loading Values of different busses.

Table 1: Load characteristics

Buses measurement	kV	MVA	MW	MVAR
Slack Bus220	220	9000sc	48.113	26.847
L1-20	30	20	18	8.718
L2-20	30	20	18	8.718
L1-1.6	0.4	1.6	1.28	0.96
L-F1	0.63	3.15	2.835	1.373
L-F2	0.63	3.15	2.835	1.373
L-F3	0.63	3.15	2.835	1.373
L-F4	0.63	3.15	2.835	1.373

Table 2: load flow results

Bus		Voltage		Generation		Load		Load flow					XFMR
ID	kV	%Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Bus-L&C	0.400	98.697	-7.4	0	0	1.247	0.818	Bus11KV	-1.247	0.818	2181	-83.6	
Bus-M	6.000	95.060	-6.4	0	0	2.484	1.382	Bus11KV	-2.484	-1.382	287.7	87.4	
Bus-SF1	1.000	94.084	-7.5	0	0	2.552	1.236	Bus11KV	-2.552	-1.236	1739.4	90.0	
Bus-SF2	1.000	94.084	-7.5	0	0	2.552	1.236	Bus11KV	-2.552	-1.236	1739.4	90.0	
Bus-SF3	1.000	94.084	-7.5	0	0	2.552	1.236	Bus11KV	-2.552	-1.236	1739.4	90.0	
Bus-SF4	1.000	94.084	-7.5	0	0	2.552	1.236	Bus11KV	-2.552	-1.236	1739.4	90.0	
Bus11KV	11.000	96.887	-4.8	0	0	0	0	Bus-SF1	2.567	1.391	158.2	87.9	
								Bus-SF2	2.567	1.391	158.2	87.9	
								Bus-SF3	2.567	1.391	158.2	87.9	
								Bus-SF4	2.567	1.391	158.2	87.9	
								Bus-L&C	1.259	-0.748	79.3	-86.0	
								Bus-M	2.491	1.478	156.9	86.0	5.000
								Bus-30KV-B	-7.009	-3.147	416.2	91.2	
								Bus-30KV-B	-7.009	-3.147	416.2	91.2	
Bus-30KV-A	30.000	98.876	-2.7	0	0	0	0	Bus-30KV-B	-7.009	-3.147	416.2	91.2	
								BusL1-20MVA	17.550	8.5538	379.9	89.9	
								Bus-30KV-B	7.030	3.472	152.6	89.7	
								BusL1-20MVA	17.550	8.5538	379.9	89.9	
								Bus220KV	-24.580	-12.010	532.5	89.0	
								Bus220KV	-24.580	-12.010	532.5	89.0	
Bus-30KV-B	30.000	98.765	-2.8	0	0	0	0	Bus-30KV-A	-7.026	-3. 460	152.6	89.7	
								Bus-30KV-A	-7.026	-3. 460	152.6	89.7	
								Bus11KV	7.026	-3. 460	152.6	89.7	
								Bus11KV	7.026	-3. 460	152.6	89.7	
*Bus220KV	220.000	101.546	0.0	49.249	27.056	0	0	Bus-30KV-A	24.624	13.528	72.6	87.6	
								Bus-30KV-A	24.624	13.528	72.6	87.6	
BusL1-20MVA	30.000	98.765	-2.8	0	0	17.533	-8.491	Bus-30KV-A	-17.533	-8.491	379.9	90.0	
BusL2-20MVA	30.000	98.765	-2.8	0	0	17.533	-8.491	Bus-30KV-A	-17.533	-8.491	379.9	90.0	

Table.2 summarizes the load flow evaluation throughout the overall grid at different bus level depicting a unique voltage or a bus load. Attributed ID names allow referring voltage level aiming to carry out power transfer and quantities of the last sited ones and detecting where there is an abnormality.

Bus-M presents an under voltage 5.3 in place of 6 KV as a critical alert from load flow analysis

Table 3: loading summary of demand of the total generation

Table.3 loading summary of demand of the total generation , loding and demand	MW	Mvar	MVA	%PF
Source (swing Buses):	59.702	31.816	67.650	86.13 PF Lagging
Source (non-Swing Buses):	0.000	0.000	0.000	
Total Demand:	59.448	27.237	65.391	89.69 PF Lagging
Total Line Charging:	0.000	0.000		
Apparent Losses:	0.253	4.579		
System Mismatch:	0.000	0.000		

Table.3 show clearly that voltage is within regulatory limits (95%-105%) especially in the grid part. Real power in swing bus is 95.44MW while reactive power is 27.23 Mvar and power losses (253KW, 4.57Mvar). Power factor is 86.7 % which is less than the standard set by the utility 92 %.

3.2 Harmonic analysis

Harmonic analysis is performed on the under consideration entire power system. We would like to measure power quality at different busses at the grid, under different conditions. After collecting the data we need for evaluating harmonic distortion. The above plots show the line to line voltages and their equivalent FFT harmonic representations.
The Voltage waveform and its harmonic spectrum captured at the monitoring bus 220KV are shown in Fig. 5 and Fig. 6 respectively. For the generation side we have a good voltage waveform with minimum THD les than 0. 1%

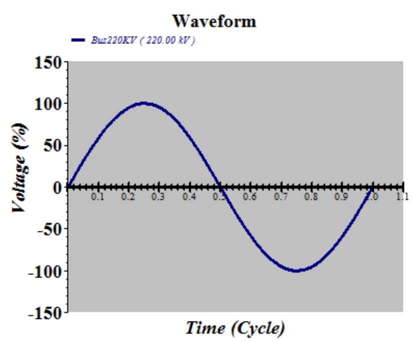

Fig. 5 Voltage Waveform at 220KV

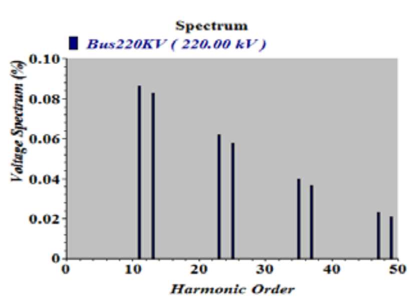

Fig. 6 Voltage Spectrum at 220KV

Similarly, The Voltage waveform signal and harmonic spectrum measured at Bus 30KV-A is shown in Fig. 7 and Fig. 8 respectively. THD is less than 0.9% of the fundamental magnitude.

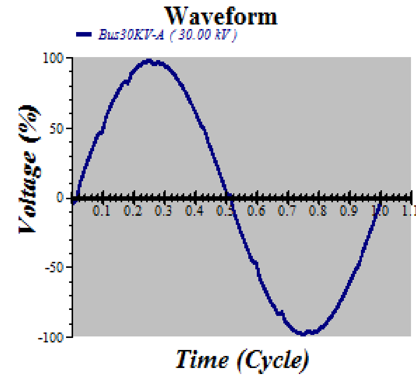

Fig. 7 Voltage Spectrum at Bus 30KV-A

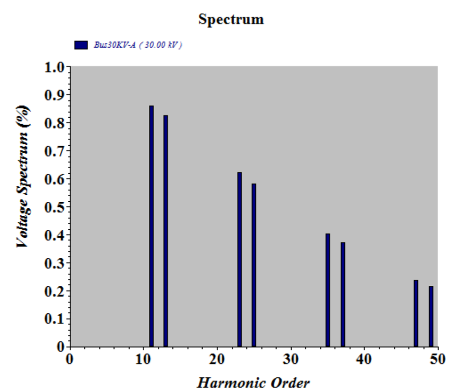

Fig. 8 Voltage Spectrum at Bus 30KV-A

Voltage waveform and its harmonic spectrum captured at the monitoring bus 30KV-B are shown in Fig. 9 and Fig. 10 respectively. For 30KV-B we have a good voltage waveform with minimum THD les than 0.9%.

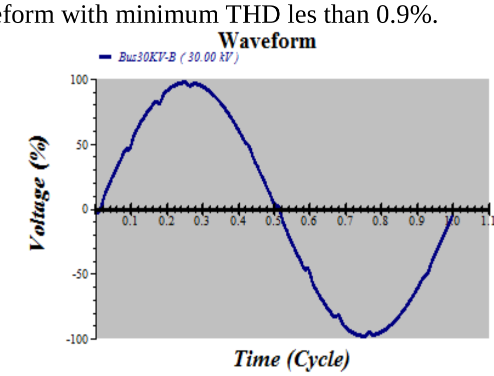

Fig. 9 Voltage Waveform at 30KV-B

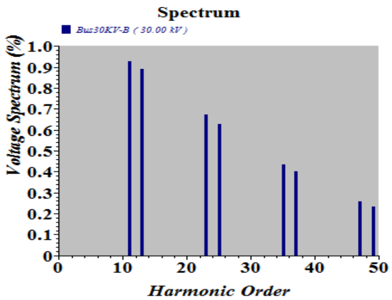

Fig. 10 Voltage Spectrum at 30KV-B

The monitoring bus 11KV represent the common bus of the plant.Voltage waveform and its related spectrum are shown in Fig.11 and Fig.12 respectively. Herein we are within acceptable limits; THD is slightly above 3%.

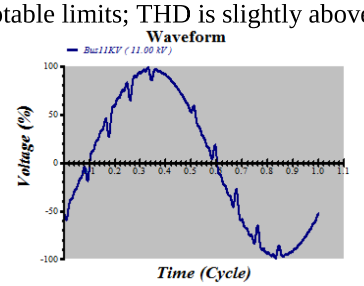

Fig. 11 Voltage Waveform at 11KV

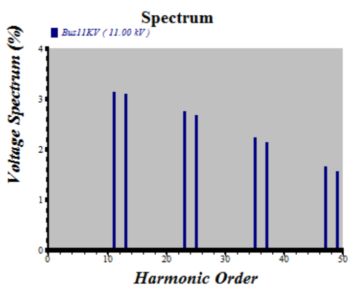

Fig. 12 Voltage Spectrum at 11KV

The Bus-M is the common bus for the connected 6 motors at 6 KV voltage level. Fig.13 and Fig.14 respectively show the THD level which presents 2.5 %.

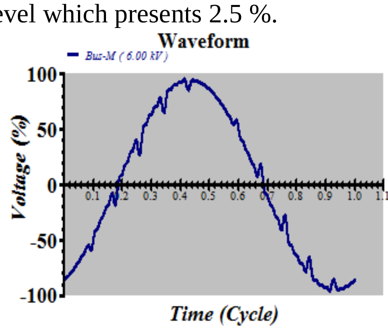

Fig. 13 Voltage Waveform at Bus-M

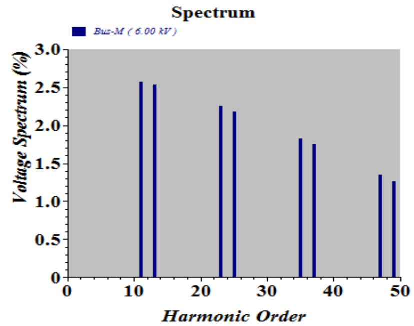

Fig. 14 Voltage Spectrum at Bus-M

The SF-1 is the bus where connected 1.2MVA load and a 350KVA capacitor bank to compensate reactive power. The plant is suffering from cutoff problems and transformer saturation phenomenon. Then we get sure according to FFT analysis that this is highly suspected to be the origin of the issue. Fig.15 and Fig.16 respectively demonstrate the THD level which presents 8% representing maximum allowed limit.

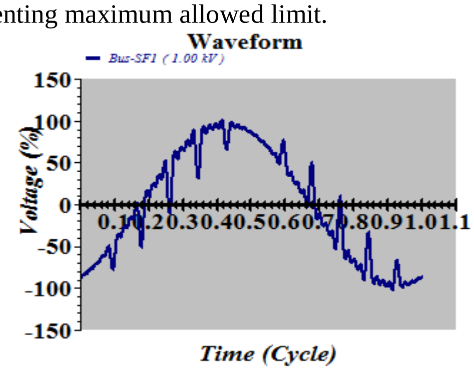

Fig. 15 Voltage Waveform at Bus SF-1

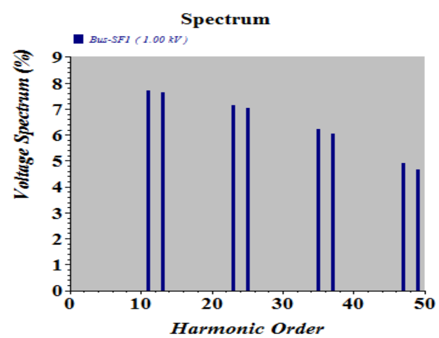

Fig. 16 Voltage Spectrum at Bus SF-1

Table 4: summary of THD bus levels

Bus													
		Current Distortion											
From Bus ID	To Bus ID	Fund Amp	RMS Amp	ASUM Amp	THD %	TIF	IT Amp	ITB Amp	ITR Amp	TIHD %	TSHD %	THDG %	THDS %
Bus-L&C	Bus11KV	2145.37	2153.99	2536.53	8.97	241.82	520873.80	520873.80	0.00	0.00	0.00	8.97	8.97
Bus-M	Bus11KV	291.67	292.74	307.60	2.27	75.89	22217.40	22217.40	0.00	0.00	0.00	2.27	2.27
Bus-SF1	Bus11KV	1770.53	1781.96	2227.24	11.38	384.78	685660.10	685660.10	0.00	0.00	0.00	11.38	11.38
Bus-SF2	Bus11KV	1770.53	1781.96	2227.24	11.38	384.78	685660.10	685660.10	0.00	0.00	0.00	11.38	11.38
Bus-SF3	Bus11KV	1770.53	1781.96	2227.24	11.38	384.78	685660.10	685660.10	0.00	0.00	0.00	11.38	11.38
Bus-SF4	Bus11KV	1770.53	1781.96	2227.24	11.38	384.78	685660.10	685660.10	0.00	0.00	0.00	11.38	11.38
Bus11KV	Bus-SF1	160.96	162.00	202.48	11.38	384.78	62332.73	62332.73	0.00	0.00	0.00	11.38	11.38
	Bus-SF2	160.96	162.00	202.48	11.38	384.78	62332.73	62332.73	0.00	0.00	0.00	11.38	11.38
	Bus-SF3	160.96	162.00	202.48	11.38	384.78	62332.73	62332.73	0.00	0.00	0.00	11.38	11.38
	Bus-SF4	160.96	162.00	202.48	11.38	384.78	62332.73	62332.73	0.00	0.00	0.00	11.38	11.38
	Bus-L&C	78.01	78.33	92.24	8.97	241.82	18940.87	18940.87	0.00	0.00	0.00	8.97	8.97
	Bus-M	159.64	156.68	167.78	2.27	75.89	12118.58	12118.58	0.00	0.00	0.00	2.27	2.27
	Bus-30KV-B	422.71	423.89	494.99	7.46	25687	110155.70	110155.70	0.00	0.00	0.00	7.46	7.46
	Bus-30KV-B	422.71	423.89	494.99	7.46	256.87	110155.70	110155.70	0.00	0.00	0.00	7.46	7.46
Bus-30KV-A	Bus-30KV-B	154.99	155.42	181.49	7.46	256.87	40390.43	40390.43	0.00	0.00	0.00	7.46	7.46
	BusL1-20MVA	373.97	374.01	388.19	1.48	69.58	2623.19	26023.19	0.00	0.00	0.00	1.48	1.48
	Bus-30KV-B	154.99	155.42	181.49	7.46	259.87	40390.43	40390.43	0.00	0.00	0.00	7.46	7.46
	BusL1-20MVA	373.97	374.01	388.19	1.48	69.58	26023.19	26023.19	0.00	0.00	0.00	1.48	1.48
	Bus220KV	528.96	529.04	548.30	1.78	49.62	26251.91	26251.91	0.00	0.00	0.00	1.78	1.78
	Bus220KV	528.96	529.04	548.30	1.78	49.62	26251.91	26251.91	0.00	0.00	0.00	1.78	1.78
Bus-30KV-B	Bus-30KV-A	154.99	155.42	181.49	7.46	259.87	40390.43	40390.43	0.00	0.00	0.00	7.46	7.46
	Bus-30KV-A	154.99	155.42	181.49	7.46	259.87	40390.43	40390.43	0.00	0.00	0.00	7.46	7.46
	Bus11KV	154.99	155.42	181.49	7.46	259.87	40390.43	40390.43	0.00	0.00	0.00	7.46	7.46
	Bus11KV	154.99	155.42	181.49	7.46	259.87	40390.43	40390.43	0.00	0.00	0.00	7.46	7.46
Bus220KV	Bus-30KV-A	71.13	72.14	74.77	1.78	49.62	3579.81	3579.81	0.00	0.00	0.00	1.78	1.78
	Bus-30KV-A	71.13	72.14	74.77	1.78	49.62	3579.81	3579.81	0.00	0.00	0.00	1.78	1.78
BusL1-20MVA	Bus-30KV-A	373.97	374.01	388.19	1.48	69.58	26023.19	26023.19	0.00	0.00	0.00	1.48	1.48
BusL2-20MVA	Bus-30KV-A	373.97	374.01	388.19	1.48	69.58	26023.19	26023.19	0.00	0.00	0.00	1.48	1.48

Table 5: Critical warnings

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Harmonic
Bus-SF1	Bus	Exceeds Limit	10.00	Bus THD	19.93	199.3	Total
Bus-SF2	Bus	Exceeds Limit	10.00	Bus THD	19.93	199.3	Total
Bus-SF3	Bus	Exceeds Limit	10.00	Bus THD	19.93	199.3	Total
Bus-SF4	Bus	Exceeds Limit	10.00	Bus THD	19.93	199.3	Total

Table.4 and table.5 show the THD% levels and critical limits violation. All THD buses level remain acceptable except SF1, SF2, SF3, SF4 manifest a harmful level of THD which are deplumed using MLI controls of inverters before feeding loads inside the factory.

3.3 Motors Starting Analysis

Motor starting analysis is performed on Induction motor and different effects like % slip, starting current, starting torque, terminal voltage, bus voltage and accelerated torque on the power system under study are recorded during the starting of the motor. Fig. 17 shows the single line representation of induction motor when simulated in ETAP for motor starting analysis.

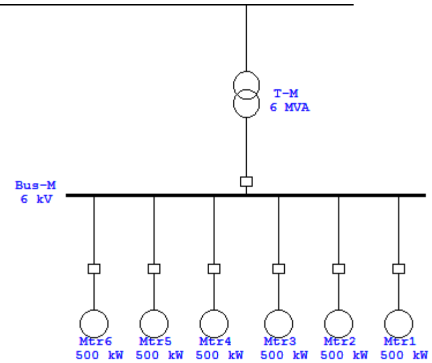

Fig. 17 Simulated model for Motor starting study

In the above section we present the motors starting plot results in order to assess common bus voltage, output current, demanded and output real and reactive powers, % motor slip, Motor terminal voltage and % of acceleration torque.

In this section we will introduce the dynamic motor starting study which is the same for the 5 motors. Fig. 18 represents the equivalent circuit model with its appropriate impedances. The second curve Fig. 19 shows the torque-slip curve calculated based on the circuit.

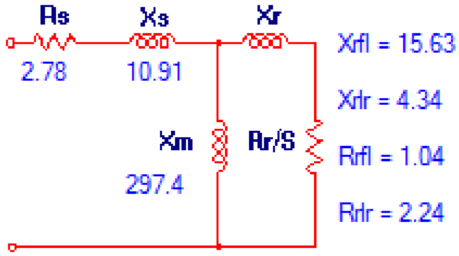

Fig. 18 Induction motors used for simulation

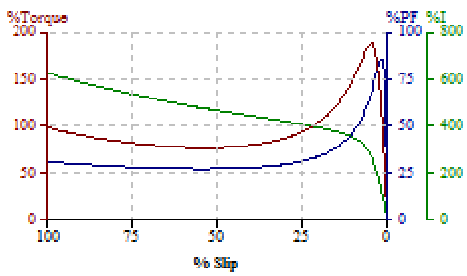

Fig. 19 Induction motors used for simulation

The connected load could be specified as a polynomial function:

$$\%\text{Torque} = A \times W^2$$

This is a function of speed and torque, in were the brown line shows the motor torque and the green line shows the connected load torque. As we can see from the curves the required load torque is lower than the available machine torque indicating that we operate under normal operating conditions the model should accelerate successfully.

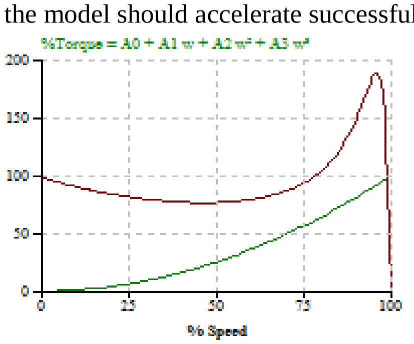

Fig. 20 Motor and load torque

We have taken some of the result plots including: the nominal bus voltage in dynamic mode where they are focalized in the range of 95% of the nominal voltage seen for the terminal motor voltage in Fig. 21 Further deeps at starting time motors impact the same bus as we see in the above curves Fig. 22.

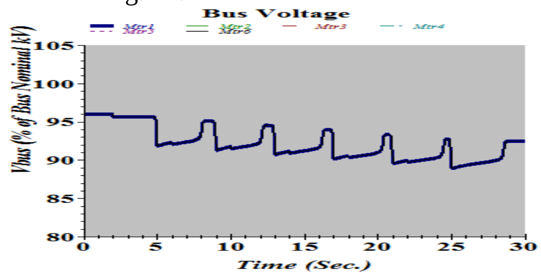

Fig. 21 Motors Bus voltages in %.

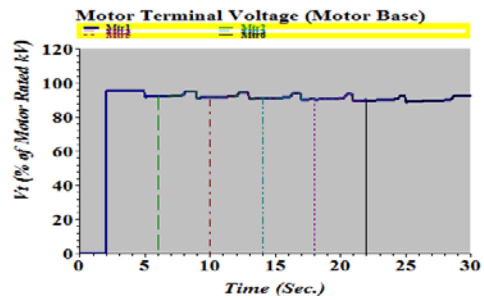

Fig. 22 Different Motors Buses voltages

These are different effects observed on the power system during motor starting analysis.

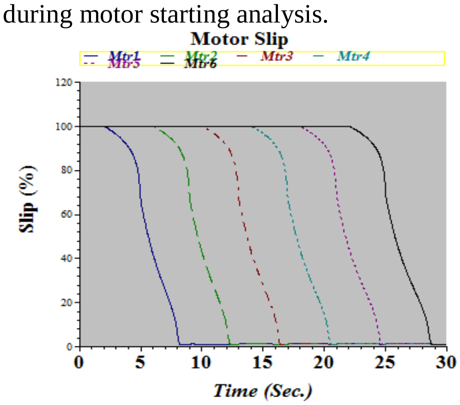

Fig. 23 Different Motors slip

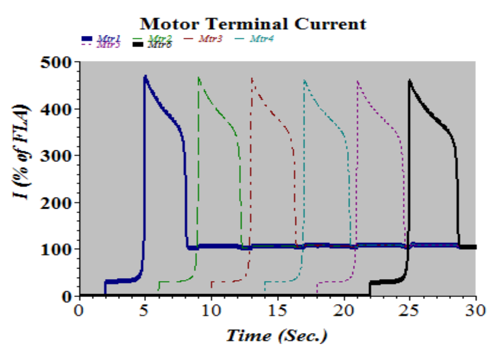

Fig. 24 Motors current

Fig. 23 show the motor slip accelerating accordingly for the 6 motors at times t=2, 6, 10, 14, 18, 22s. Taking an acceleration time of 4 s.

In Fig. 24 The motor currents manifest 5 times their nominal current at the beginning of their working before they get stabilized at 30s heuristic point.

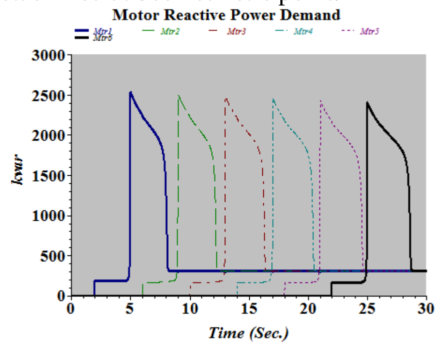

Fig. 25 Different Motors Reactive Power Demand

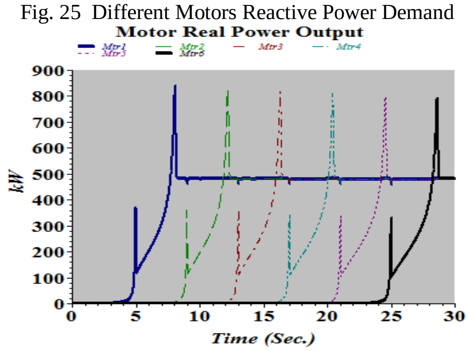

Fig. 26 Different Motors Real Power Output

A significant amount of active and reactive powers needed at the beginning for the functioning of cascade motors before they regain the permanent consumption, 500KW, 470Kvar equivalent to the demand in term of active and reactive power. Electrical signal waves could be assessed and monitored at any bus over the grid using this performed design. Moreover, grid operators, Academia, Industries and electrical power stake holders in generally have the opportunity to be acknowledged about their overall electrical state and be in optimal conditions for each purpose. Once all analysis done and the overall system are totally monitorable and controllable, conventional grid migration into smart grid will be easier in the ground reality.

4. Conclusions

The electrical power systems, information theory and calculator combination lead to born new generation of simulation performance close to reality. It opens new pathways for complex and embedded Electrical Power Systems design and validation. Several analyses have been performed in this work like load flow or THD in static stability or motors start up in transient one. As a future work we propose to overcome extracted issues with two methods to improve the under voltage and global THD level problems in addition to powers disequilibrium in order to choose the most suited to be installed in the factory and a comparison of before and after states**.**

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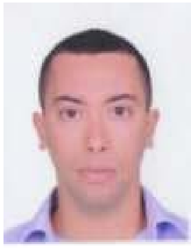

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