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Effect of Voltage Sag and Voltage Unbalance on Induction Motor Drives

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Abstract: Voltage sags and unbalance pose a serious power quality issue for the electric power industry. The induction motor has widely used the machine in process industries (around 70%). In this paper, the performance of the Induction Motor Drive (IMD) under the condition of voltage sag and voltage unbalance is studied. The drive model is modelled in MATLAB/Simulink environment and the simulation results are obtained for time varying load. The performance of the IMD under different indexes viz. variation in current, speed and torque is investigated under varying sag depths and durations. The ripples in speed and torque are also investigated under unbalance conditions

Keywords: Induction Motor, Voltage Sag, Voltage Unbalance.

I. INTRODUCTION

The most commonly used machines are three-phase induction motors in various drives of electrical. Mostly in industrial loads (approx 70%), induction motors are used. The induction motor is a highly efficient electrical machine when running near to its rated speed and torque. There are several factors affecting induction motor efficiency such as; a)Partial Load, b)Power Quality Disturbances, c)Improper Design, d)Non-sinusoidal supply, e)Rewinding effects.

The main factor of service fidelity to both utility and users has become the power quality. Due to industrial components becoming more sensitive to minor voltage variations, the power quality has become more severe. Voltage sag and voltage unbalance are the most critical power quality perturbations to be dealt with by the industrial areas, as it can cause severe process interruptions and results are a deduction in quality of products and heavy economic loss in Induction motor. The main signal of a power-quality problem is a distortion in the waveform voltage of the source from a sinusoidal wave or in the amplitude from any set reference level, or a complete distortion. Due to harmonics, interruptions can be occurred in the current or by the changes in the main voltage system. The disturbance in the voltage supplied by the source can go for a period of few milliseconds to period of hours in a cycle [5].

Voltage sag is a reduction in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute, reported the remaining voltage. The main values lie between 0.1p.u and 0.9p.u [8]. The measurement of voltage sag is stated as a percentage of the rated voltage. It is a measurement of the remaining voltage and is stated as sag to a percentage value. Thus a Voltage Sag to 70% is equivalent to 70% of rated voltage means 308Volts for rated 440 Volt systems. Voltage sag means that the complete required energy by the load is not being transferred to it. Voltage sags can occur on Utility systems both at distribution voltages and transmission voltages. Voltage sags are usually associated with system faults but can also be caused by switching heavy loads or starting large motors. Voltage sags can also be instigated by large changes in load or the starting of large motors. An induction motor can draw six to ten times its full load current during starting. This large current results in the voltage drop across the impedance of the system. If the magnitude of the current is large as compared to the available fault current of the system, the resulting voltage sag can be substantial. The switching operations associated with a temporary disconnection of supply, the flow of fault currents or the flow of inrush currents associated with the starting of motor loads can cause voltage sag in the system. These events may emanate from the public network or from the customer's system. Lightning strikes can cause voltage sags of momentary type [2].

The voltage unbalances can be caused by unbalanced loads or single phase loads that are not evenly distributed between the phases of a system with three phases. This loading can be within the facility or outdoor on the utility. So a voltage unbalanced fault may be created due to harmonics due to electronics equipment, adjustable speed drive fed from inverter, unbalanced incoming utility supply, uneven distribution of single phase load , malfunctioning of power factor correction equipment, open delta connections, unbalance transformer tank, improper tap settings of transformer, sudden changes in load conditions, faults on transmission & distribution lines, high reactive single phase loads such as welders, current harmonics due to winding arrangement & iron core nonlinear behaviour. The unlike voltage values on 3-phase circuits that may exist anywhere in a power distribution system are the unbalanced voltages. Unbalanced voltages can cause critical problems, particularly to inductive devices and motors. In the real world, the circuits with perfect voltage-balanced are not possible. Voltage Unbalanced is defined as a power quality problem where the voltage in 1 or 3 phases gets increased or decreased in phase & magnitude above/below tolerance limit. In a three-phase system, voltage unbalance takes place when the magnitudes of phase or line voltages are not equal and the phase angles are different from the balanced conditions, or both [14].There are mainly two methods to calculate voltage unbalance, the first method consists of expressing the negative sequence voltage as a percentage of the positive sequence voltage and the second method uses the maximum deviation from the average of the three line values denoted as a percentage of the average of the three line voltages.

II. UNDERSTANDING OF VOLTAGE SAG AND UNBALANCE

A. Types of Voltage Sag

The recent study indicates that 92% of all interruptions in the electrical power system are caused by voltage sags. When voltage sag occurs in the electrical system, then sensitive load often trips or shuts down. Voltage sag is of two types i.e. symmetrical and unsymmetrical. When all phase voltages are same and the phase difference is 120°, then the sag is symmetrical, otherwise, the sag is unsymmetrical [1]. Voltage sag can be classified into seven types, i.e., Type A, B, C, D, E and F. Fig.1; shows the mathematical expressions of the types of voltage sag. Table I shows the different types of voltage sag and its effect on individual phases. Furthermore, sag may be classified by their duration as Instantaneous sag (10-600ms), momentary sag (600ms-3s) and temporary sag (3s-1min).

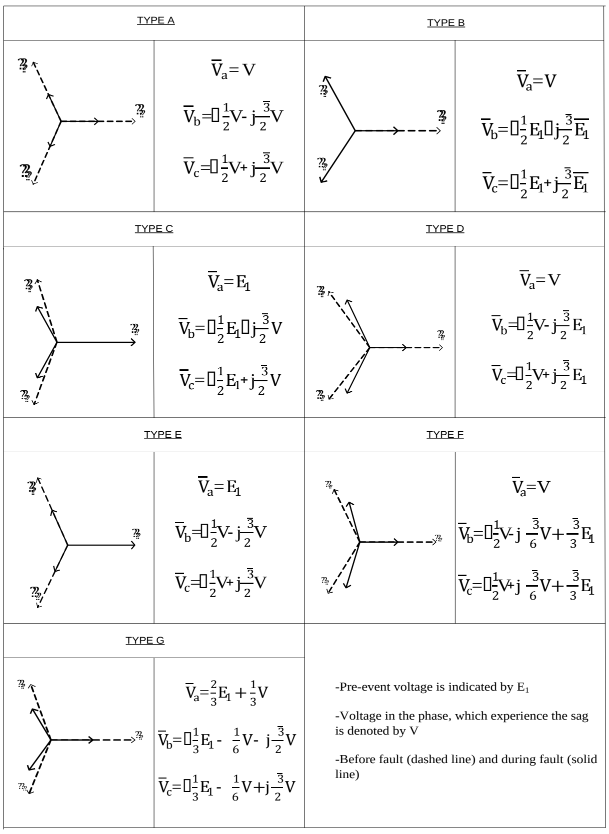

Figure1 Mathematical expressions of the types of voltage sag

Table I Different Type of Voltage Sag and Its Effect on Individual Phases

TYPE	NATURE	FAULT TYPE	PHASES OBSERVATION	
			MAGNITUDE CHANGE	PHASE CHANGE
A	Symmetrical	Three phase short circuit	Equal drop in all phases	None
B	Unsymmetrical	Phase to phase (LL)	Drop in one phase	None
C	Unsymmetrical	Phase to phase(LL)	Drop in two phases	In two phases
D	Unsymmetrical	Phase to phase(LL)	Drop in all phases	In two phases
E	Unsymmetrical	Double line to ground	Drop in two phases	None
F	Unsymmetrical	Double line to ground	Drop in all phases	In two phases
G	Unsymmetrical	Double line to ground	Drop in all phases	In two phases

B. Types of Voltage Unbalance

There subsist minute possibility of voltage variations below and above the rated value in one phase, two phase and three phase as there is a variation in operating times of three phase and single phase loads.

BOV (Balanced over-voltage) is the situation when the three-phase voltages are individually greater than the rated voltage value, BUV (Balanced under-voltage) is the situation when the three-phase voltages are individually lesser than the rated voltage value. Six types of voltage unbalance are; a) Single phase under voltage unbalance-(1ø UV), b) Two phases under voltage unbalance (2ø UV), c)Three phase under voltage unbalance (3ø UV), d) Single phase over voltage unbalance (1ø OV), e) Two phases over voltage unbalance (2ø OV), f)Three phases over voltage unbalance (3ø OV).

Single phase under voltage; when the voltage of one phase gets decrease, then it is called as single phase voltage (1Φ −UV). In the power system when a one-phase load not being enough compensator, then the voltage domain of that phase is less than the other two phases. Two phases under voltage: when voltage decreases of two different phases, then it is called as two phases under voltage (2Φ −UV). In the power system, this occurs, when there are two uneconomical loads in two phases and a non-existence compensator. Three phases under voltages: when voltage decreases of all the three phases, then it is called as three phase voltage (3Φ −UV). In the power system, this occurs, when the effect of an uneconomical and unbalance load of each phase. Single phase over voltage: when voltage increase of one of the phases out of three phases then it is called as single phase voltage (1Φ −OV). If one of the three phase voltage is highly compensated for holding on the power network voltage, the voltage of this phase will become more than the rated level. Two phases of voltage: when the voltage gets increased in two phases, then it is called as two phases over voltage (2Φ −OV). When two phases become highly compensated, the voltages of these two phases will become more than the rated level. Three phases of voltage: when the voltage gets increased of all the three phases, then it is called as three phase over voltage (3Φ −OV). When the three phase voltages will be compensated unequally, then the voltages of each phase will be greater than the rated level [20].

III. SIMULATION RESULTS AND DISCUSSION

Simulations are executed for 420V, 50Hz, 2poles, 1-hp Induction motor whose equivalent circuit parameters are R_r=8.9838Ω, R_s=11.124Ω, L_s=0.03336H, L_r=0.03336H, L_m=0.49045H, Moment of Inertia=0.0018Kg-m^2, Rated Torque=2.5Nm, Rated Speed=300rad/s, Friction Factor=0Nm-s.

The simulation of Induction Motor is done under the condition when voltage sag occurs in the system for the constant duration at different loads and the results of the simulation are presented below.

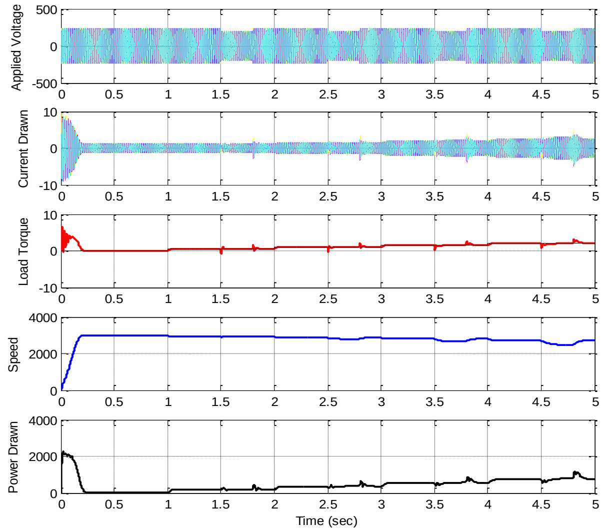

Figure 2 Induction motor operating under voltage sag condition for constant duration at different loads

Fig.2; shows applied voltage, current drawn, load torque and power drawn for Induction Motor connected to 3-phase supply having voltage sag for the constant duration at different loads. At light loads, the effect of voltage sag is almost negligible. When the load increases, the speed and the current will get reduce and the power drawn will increase according to the increase in the percentage of the load. After removing the sag, the speed and the current will get an increase for a slight moment and then it comes to its stable position.

Table II shows the effect of sag depth and duration when the Induction motor is fully loaded. For very less duration of sag, there is no effect when the depth is 90%-70%. As the duration is increased and sag depth is high, then also there is no effect of sag. When the duration is increased and depth is also decreased from 60%-10%, then there will be some effect on the motor and when the duration is very high and depth is low, the motor will get shutdown.

Different simulations are also carried out at 25%, 50%, and 75% load and it is analyzed that with the decrease in load, the chances of failure of motor gets reduce but this condition is not good as the system efficiency gets reduced with the reduction in load and there is no effect on the motor, when the duration is very low and the sag depth is varied even if the load is varied.

Table II: Variation of sag depth and duration

SAG DEPTH →

SAG DURATION ↓

	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
0.5T	X	X	X	X	X	X	X	X	X
1T	X	X	X	X	X	X	X	X	Y
2T	X	X	X	X	X	Y	Y	Y	Y
3T	X	X	X	Y	Y	Y	Y	Y	F
4T	X	X	X	Y	Y	Y	Y	F	F
5T	X	X	X	Y	Y	Y	F	F	F
10T	X	X	X	Y	Y	F	F	F	F
15T	X	X	X	Y	F	F	F	F	F
20T	X	X	X	F	F	F	F	F	F
25T	X	X	X	F	F	F	F	F	F

In the table shown above,

X depicts that the system is running without reduction in speed and torque

Y depicts that the system is running with reduction in speed and torque

F depicts that the system gets fail or shutdown

The simulation of Induction motor when voltage unbalances occurs is shown below:

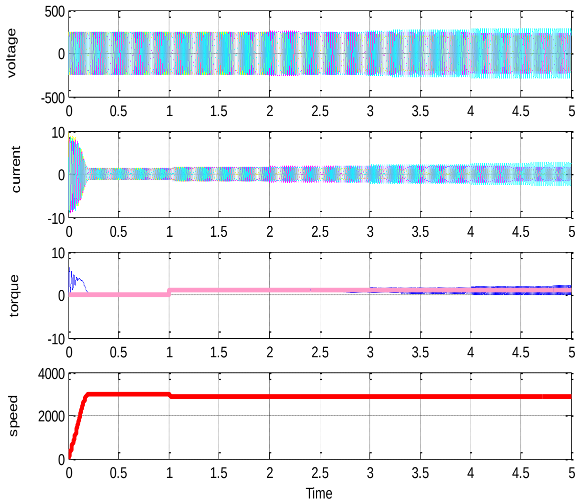

Figure 3 Voltage Unbalance

Fig. 3 shows the condition when voltage balance occurs in Induction motor. When the voltage of three phases are given in the different time span with 3 repeating sequence parameters then the changes in the torque and current waveform is visible .from time 0 to 1 (sec) there is no change due to balance supply and after 2 seconds there is a change in current, torque and speed waveform. To generate unbalance and to study its effect on load i.e. Induction Motor, under balance and over balance have been introduced in 1 phase, 2 phase and 3 phase for same positive sequence voltage for different voltage unbalance conditions, to find V_a, V_b, V_c *and* V_p for 2% voltage unbalance factor (VUF).

Table III Unbalance voltage

	V_a	V_b	V_c	V_p
3 phase UV	202	208	231	370.02
2 phase UV	207	220	242	386.45
1 phase UV	213	242	242	402.59
Balance	242	242	242	419
1 phase OV	272	242	242	436.65
2 phase OV	275	268	242	453.39
3 phase OV	288	276	250	470.17

CONCLUSION

In power system operations, financial losses are needed to be avoided. It is very important to keep the equipment's under process to be running without any interruption. From different power quality interruptions, voltage sags and unbalance are most common and result in a high economical loss because of voltage sag and unbalance cause mal-operation of the electrical equipment or the machine. The occurrence of voltage sag and unbalance events is far more than the number of power interruptions. Therefore, for specific users, the economic losses caused by voltage sag and unbalance events may even be greater than the cost associated with power interruptions. Variation of motor's current, speed, output torque and output power and variation of sag depth and duration at different loads is analyzed during voltage sag and unbalance by using MATLAB/SIMULINK software, simulation result has been analyzed. It is analyzed that with the decrease in load, the condition of failure of the machine gets reduced but the motor can't be run at the lightly loaded condition as the efficiency of the motor gets reduced.

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