Probabilistic Trip estimation

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Contents

Declaration

Certificate From HOD

Certificate From Supervisor

Acknowledgements

Abstract

Introduction

6.1 Voltage sag

Voltage sag is one of the most significant power quality sues that can affect the majority of sensitive equipments like personal computers (PC), adjustable speed drives (ASD), programmable logic controllers (PLC). Voltage sag is defined as a decrease in rms voltage or current at the power frequency for durations of 0.5 cycle to 1 min. Typical values are from 0.1 to 0.9 pu.[IEEE Recommended Practice for Evaluating Electric Power System Compatibility With Electronic Process Equipment]. Voltage sags are present in power systems, but only during the past decades customers are becoming more sensitive to the inconvenience caused [Pirjo Heine and Matti Lehtonen, Voltage sag distributions caused by power systems faults, IEEE Transactions on Power Systems, vol.18, No.4, pp.1367-1373, November 2003]. Voltage sag can cause serious problems to sensitive loads, because these loads often drop off-line due to voltage sag. Out of the various disturbances that effect the power quality, voltage sag happens to be the most frequent disturbance. If a voltage sag occurs for a longer duration it is called an undervoltage.

Characteristics of Voltage sags:

1. **Magnitude**:- The minimum value of Vrms(1/2) recorded during a voltage sag. The magnitude is expressed as a value in volts or as a percentage or per-unit value of the declared voltage or sliding-reference voltage.[IEEE Guide for Voltage Sag Indices]

2. **Duration**:- The voltage sag duration is nothing but the period of time in which the voltage is lower than the stated limit; normally sag duration is less than 1 second [IEEE Std. 493, 1997]. The voltage sag starts when at least one of the rms voltages drops below the sag-starting threshold. The sag ends when all three voltages have recovered above the sag-ending threshold.

3. **Unbalance of sag**:- In the power system the faults are classified as symmetrical (balanced) and unsymmetrical (unbalanced) depending on the type of fault. If three phase fault occurs, the sag will be symmetrical but if the fault is single phase, double phase or double phase to ground faults the sag in three phases will not be symmetrical.

4. Point on wave of sag initiation.

Types of Voltage Sag:

1. **Single phase sags**:- These are frequently occurring voltage sags and are basically due to the phase to ground faults.

2. **Phase to phase sags:** The two phase or phase to phase sags are caused by tree branches, adverse weather, animals or vehicle collision with utility poles.

3. **Three phase sags:** - These sags are caused by switching or tripping of a 3 phase circuit breaker.These sags are caused by switching or tripping of a 3 phase circuit breaker, switch or recloser which will create three phase voltage sag on other lines fed from the same substation.

Following are some of the causes for the occurrence of voltage sag:-

1. Starting of motors can cause a voltage sag as a large amount of current will be drawn during starting when compared to current drawn while running at rated speed.

2. Excessive or sudden load changes can cause a voltage sag.

3. When a fault occurs there will be voltage sag until the protective switch gear operates.

6.2 Voltage Tolerance Curves

6.2.1 Automatic Speed Drives:

An ac ASD controls the speed of an induction or synchronous motor by converting fixed frequency/fixed magnitude ac mains supply voltage to a variable frequency/variable magnitude voltage at the motor terminals. The ASDs are three-phase equipment and d ifferent combinations of three phase voltages during the sags have different effects on their operation. Testing of ASDs was conducted with the following three types of voltage sags:

1. Three-phase balanced voltage sags.

2. Generalized two phase voltage sag.

3. Generalized single phase voltage sag.

To illustrate this, the test procedure used with rectangular voltage sags is described:

1. The drive was first connected to the voltage sag generator (VSG) which supplies the drive with rated input characteristics. Controlled motor was started unloaded.

2. The motor was loaded with one of three load types and the selected torque. The speed of the motor was adjusted to one of the pre-selected values. One of three voltage sag types was selected for testing. The point on wave of the sag initiation and phase shift during the sag were set.

3. Voltage sags were applied in steps of 1% of rated value, starting from 0 V. For each sag magnitude, the duration of the sag was prolonged until some of drive protection systems activate the disconnection of the drive, or, if there is no disconnection, up to a few seconds. The critical sag duration was ascertained by up to 10 repeated measurements. A 510 s recovery time was allocated between the consecutive voltage sags.

4. In testing with sags for which voltage in the unsagged phase(s) was used as a parameter, this value was changed in 10% steps from 0100% of the rated value, and measurements described in step 3 were repeated.

5. The point onwave of voltage sag initiation was adjusted in steps of 15^o (from 0 to 360^o) and measurements described in step 3 were repeated.

6. The phase shift during the sag was changed in steps of 15 (from 0 to 90^o) and measurements described in step 3 were repeated.

7. The speed of the motor was changed to the next value and measurements described in step 3 were repeated (motor speeds selected for testing were: 100, 75, 50, and 25% of rated motor speed).

8. Loading torque was changed to the next value, and measurements described in step 3 were repeated. Torque values selected for testing were: 100, 75, 50, 25, and 0% of rated motor torque.

9. The load typewas changed to next of three types (i.e., constant torque load, load with linear relationship between the speed and torque, and load with quadratic relationship between the speed and torque) and measurements described in step 3 were repeated.

10. The voltage sag type was changed to the next of the three types and measurements described in step 3 were repeated.

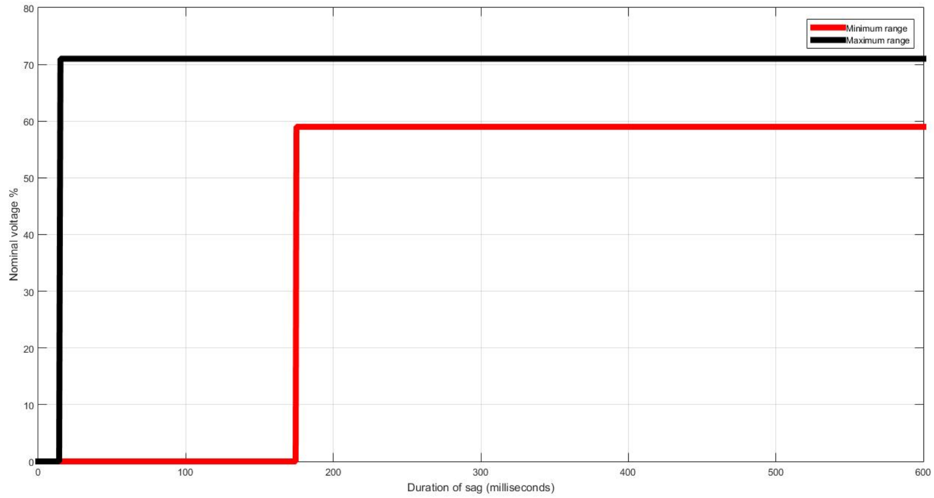

Figure 6.1: Single graph representation of drive sensitivity to various types of voltage sags

6.2.2 Personal computers (PCs)

Personal computer (PC) is a a general-purpose, rather complex electronic computing device designed to be operated by one person at a time. PCs can be implemented as real-time systems (i.e., for real-time control of various external devices), for online control of communication between two or more locations, or as a part of continuous process-control applications. Two software malfunction criteria that may result in different voltage-tolerance curves for PCs were considered in the tests: a) lockup of a read/write operation, and b) blockage of the operating system (OS). Tests were performed with rectangular voltage sags and an ideal voltage supply, as well as with nonrectangular sags occurring during the start of the large motors. The following procedure was used in tests with rectangular voltage sags.

1. The computer (with all input/output (I/O) and pointing devices connected) was switched on and allowed to boot and load the operating system.

2. Read/write operation (copying of different files from CD-ROM to the computers hard drive) was initiated.

3. Voltage sags were applied in steps of 1% of rated voltage, starting from 0 V. The point on wave of the sag initiation and the phase shift during the sag were both kept constant. For each voltage sag magnitude, the duration of the sag was progressively increased until lockup of copying operation was obtained, or the operating system was blocked, or the computer was forced to restart, or if none of the former happened up to a few seconds. The critical sag duration for each of these hardware/software criteria was ascertained by up to ten repeated measurements for each value of the sag magnitude. In cases when the tested computer had different sensitivities to voltage sags with respect to different software/hardware criteria, it would first lock up the read/write operation, then it would block the OS, and, finally, it would restart. A recovery time of 5-10 s was allocated between the consecutive voltage sags.

4. The point on wave of voltage sag initiation was adjusted in steps of 15^o (from 0 to 360^o) and the measurements described in Step 2 were repeated.

5. The phase shift during the sag was changed in steps of 15 (from 0 to 90^o) and the measurements described in Step 3 were repeated.

6.2.3 AC Coil Contactors:

Switching elements are necessary for efficient control, isolation, protection, and signaling in all electrical systems. Out of all the other switching elements contactors make possible the centralized or remote control of motors and other industrial machinery. They can be integrated easily with other important circuits to perform more complex functions such as coordinated protection, time-dependent operation, or factory automation. Contactors are designed to disconnect the load

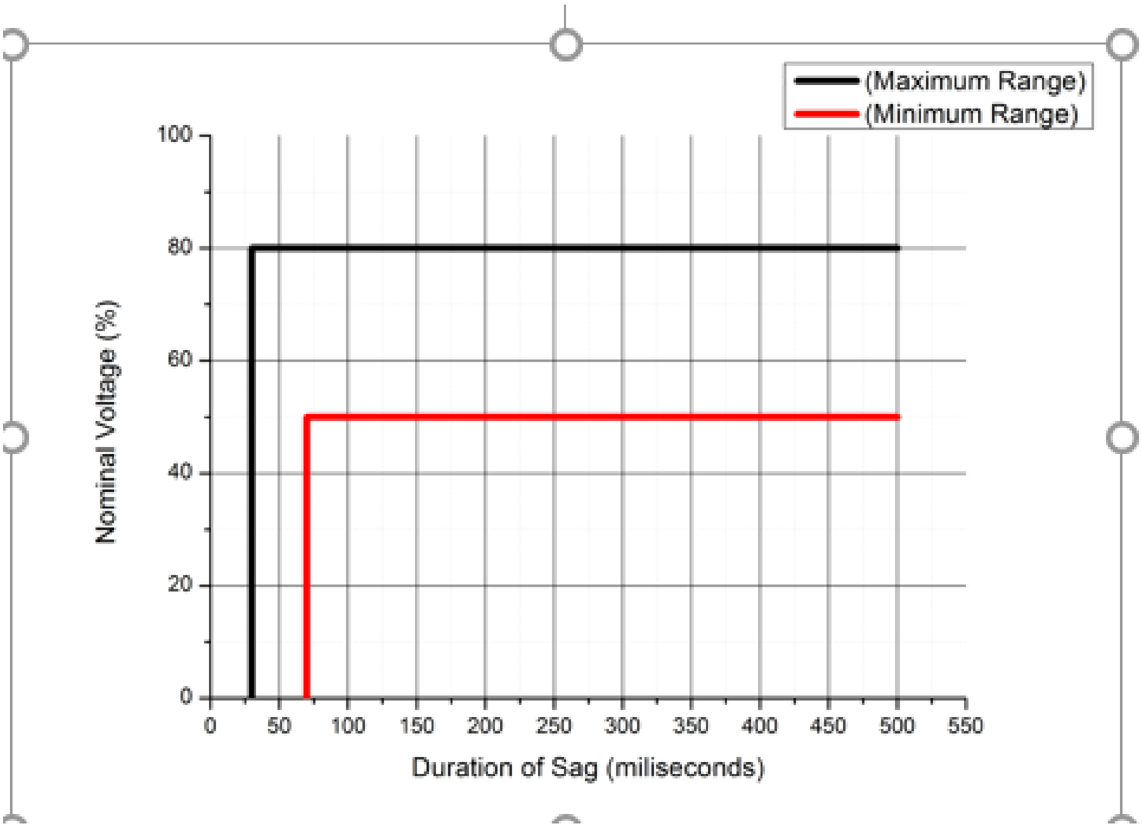

Figure 6.2: Voltage tolerance curve for Personal Computer

or circuit they control when the main power supply (control voltage) is interrupted. While testing AC Coil Contactors. Tests were performed with rectangular voltage, an ideal voltage supply, and also with two-stage sags and with sags due to the starting of large motor. The testing of the contactors was always conducted according to a well-defined procedure. For example, the procedure for testing with rectangular voltage sags proceeds as follows.

1. The contactors main electrical contacts are engaged by applying nominal voltage to the ac coil terminals (by pressing the ON button).

2. Keeping constant the values of the point on wave of sag initiation and phase shift during the sag, voltage sags are applied in steps of 1% of nominal voltage, starting from 0 V. For each voltage sag magnitude, the duration of the sag is progressively increased until contactor disengages, or up to a few seconds. The sag duration required for disengagement is ascertained by ten repeated measurements for each sag magnitude, point on wave of initiation and phase shift. After each disengagement, a minimum of 5-s recovery time is allocated before the next voltage sag is applied.

3. The point on wave of voltage sag initiation is adjusted in steps of 15^o (from 0 to 360^o) and the measurements described in step 2 are repeated.

4. The phase shift during the sag is changed in steps of 15^o (from 0 to 90^o) and the measurements described in step 2 are repeated.

6.2.4 Programmable Logic Controller (PLCs)

PLCs (Programmable Controllers) have been utilized widely as the automation backbone of industrial process sectors such as mechanical manufacturing, coal mine, chemical industry, power engineering and

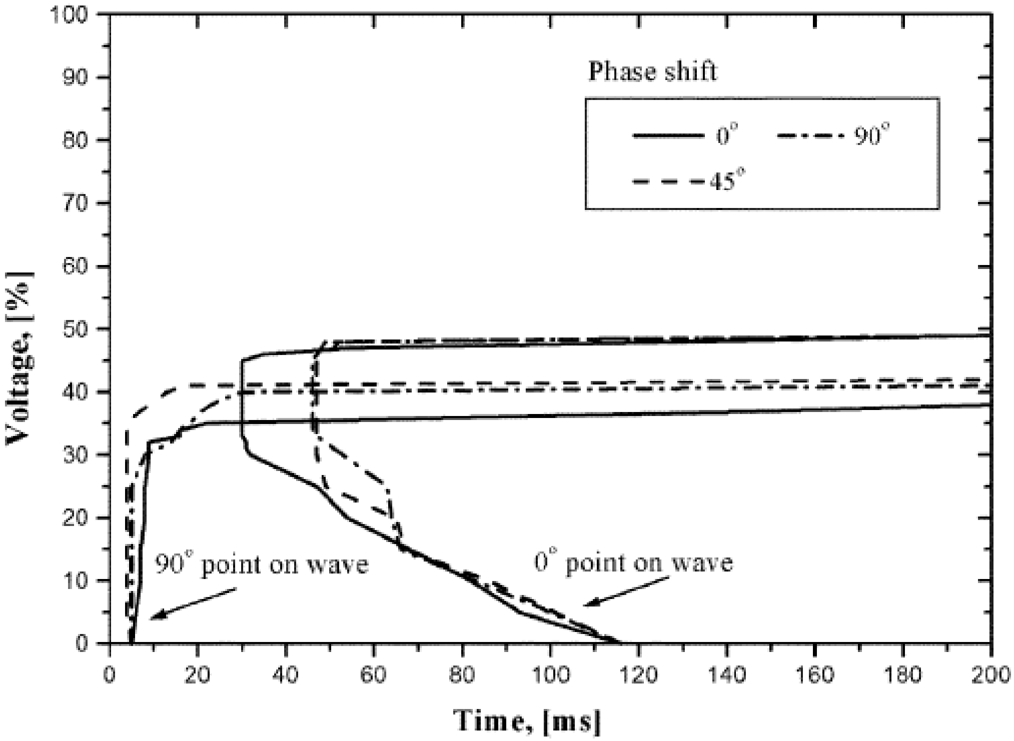

Figure 6.3: Contactor Characteristics

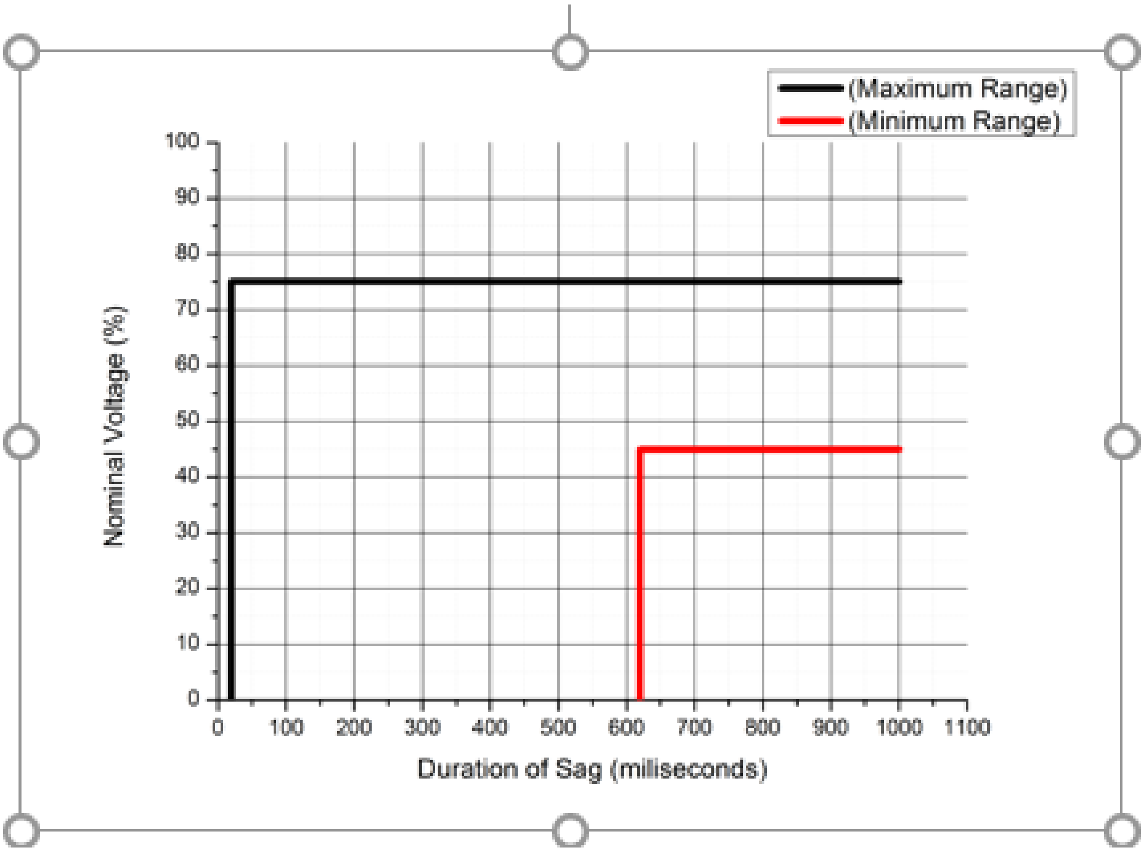

Figure 6.4: Voltage tolerance curve for PLC

so on[Chen Zhuo Exploring the Application of Programmable Logic Controller (PLC) [J] Electronics Word, no. 23, pp. 174-177, Dec., 2015]. This is an important category of equipment for industrial processes because the entire process is often under the control of these devices. The sensitivity to voltage sags varies greatly but portions of an overall PLC system have been found to be very sensitive.

6.2.5 5 HP AC Drive

This AC drive controls the speed of an induction or synchronous motor by converting fixed frequency/fixed magnitude ac mains supply voltage to a variable frequency/variable magnitude voltage at the motor

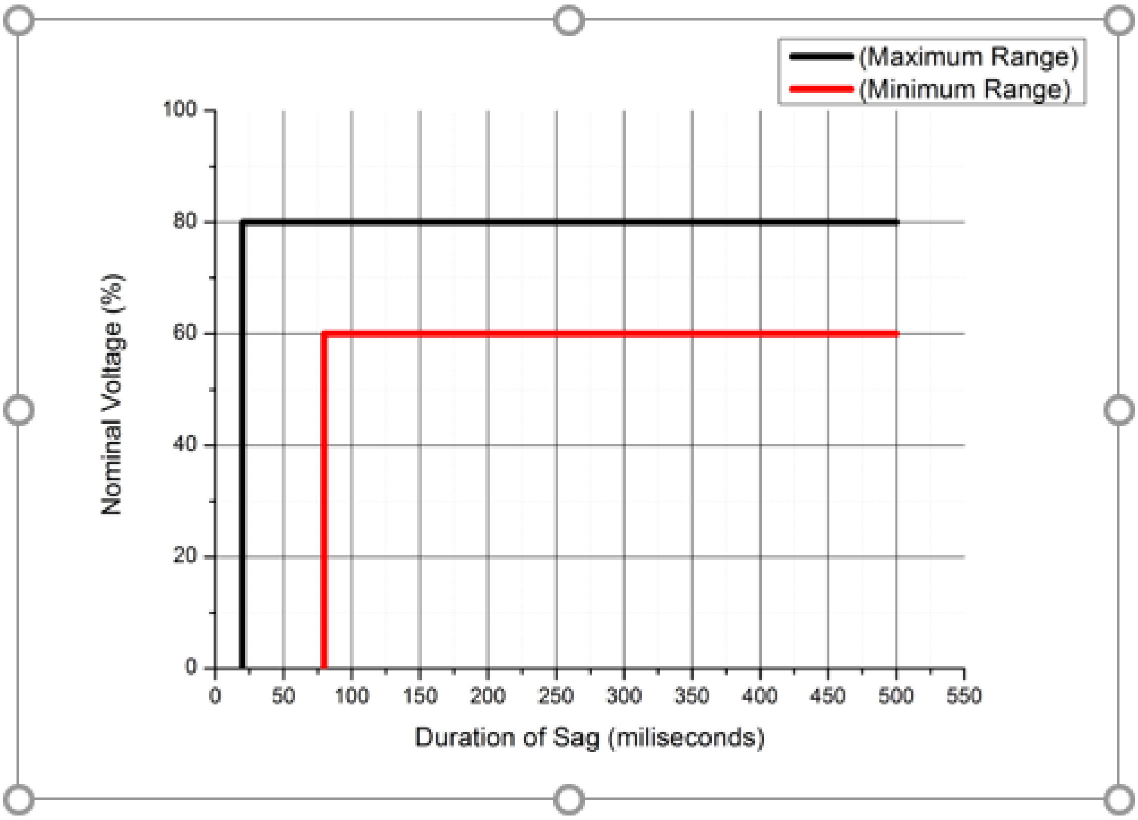

Figure 6.5: Voltage tolerance curve for 5 HP Ac Drive

terminals. Testing of 5 HP AC Drive is similar to the testing of ASD. After performing the tests we get the voltage tolerance curve of the 5 HP AC Drive

6.2.6 Motor Starter

The voltage tolerance curves for the motor starter after performing the tests is attached 6.6.

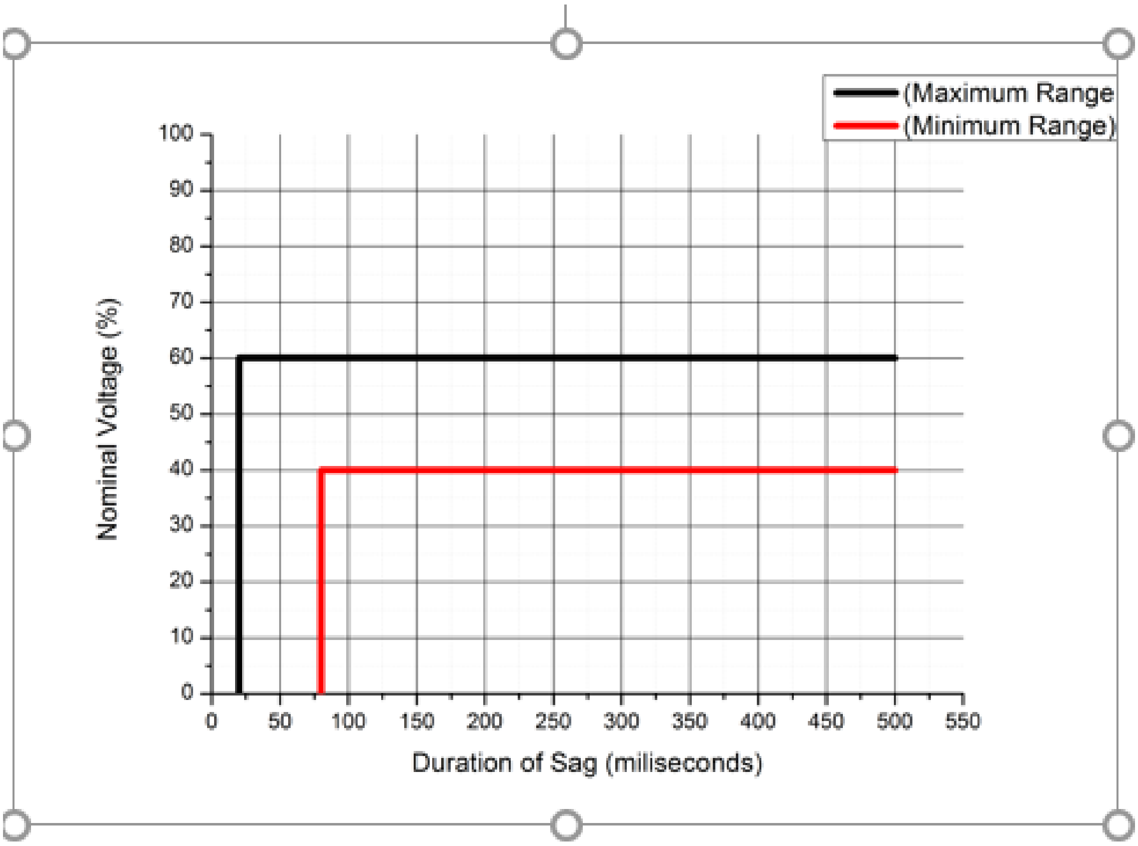

Figure 6.6: Motor Starter

Literature Review

1. (a) **Name of the chapter:** Impersonal probability assessment of equipment trip due to voltage sag.
   (b) **Name of the author:**Ying Wang, Yong Huang,Chao, Xianyong Xiao,college of electrical engineering.
   (c) **Journal:**2010, IEEE
   (d) **Summary:**The paper has provided an objective method, using maximum entropy principle to determine the stochastic distribution of any random event in mathematical field, which is a good alternative to solve the probability model of voltage tolerate curve for given sensitive equipment. As a case study PC is simulated under different conditions and compared with the traditional methods by Monte Carlo.

2. (a) **Name of the chapter:**A voltage sag index considering compatibility between equipment and supply
   (b) **Name of the author:**Cheng- Chieh Shen, student member, IEEE Chan-Nan Lu, senior member, IEEE
   (c) **Journal:**IEEE transactions on power delivery, Vol 22, No.2, April 2007
   (d) **Summary:**This paper presents a voltage sag index which would be very useful for indicating system performance experience at different locations. Fuzzy logic techniques are applied to quantify voltage sag disturbance level where retained magnitude and sag duration are the inputs to the

proposed system and the output is an index that indicated relative severity of the

3. (a) **Name of the chapter:**Assessment of financial losses due to voltage sag in an Indian distribution system

   (b) **Name of the author:**A.K Goswami, student member, IEEE C P Gupta, member, IEEE G K Singh, Department of electrical engineering, IIT Roorkee

   (c) **Journal:**2008 IEEE Region 10 colloquium and the third international conference on Industrial and information systems, Kharagpur, India, December 2008

   (d) **Summary:**This paper presents a practical implementation of the stochastic assessment of annual financial losses due to voltage sags considering the uncertainties involved with sensitivity and interconnection of equipments in individual process, customer types and location of the process in system network. The evaluation of the impact of the voltage sags at a particular site in a network involves two basic steps voltage sag assessment and economic assessment. The fault positons method is used for the stochastic prediction of voltage sag and for economic assessment of customer losses due to voltage sags, it is assumed that every nuisance trip of an industrial process requires 24 hours of restoration time. (Any other duration adopted would not affect the methodology used)The damage costs reported by various categories of customers for 24 hours long interruption are taken as the damage costs for process trips due to voltage sags.

4. (a) **Name of the chapter:**Analysis of Voltage sag severity case study in an industrial circuit

   (b) **Name of the author:**Santiago AriasGuzman,

   student member, IEEE Oscar AndresGuzman, Maria Jaramillo Gonzales, Pablo-Daniel CardonaOrozco, student member, IEEE Eduardo A. Cano Plat, senior member, IEEE Andres Felipe Salazar-Jimenez

(c) **Journal:**IEEE transactions on Industry application, Vol 53, No.2, January 2017

(d) **Summary:**This paper presents the power study carried out in an industrial distribution system. The main aim of this study was to quantify the negative impact caused by voltage sags in industrial process and its relationship to generate interruptions. Finally some good practices of industrial processes were recommended. The methodology used to calculate the sag severity is as follows: (i) Obtain the records of waveforms for a period of measurement. (ii) Calculate the retained voltage and duration of voltage sags. (iii) Calculate the voltage sag severity of voltage sags. (iv) Calculate the voltage sag severity on the studied substation as the sum of individual contributions of voltage sags.

5. (a) **Name of the chapter:**Sensitivity of AC coil contactors to voltage sags, short interruptions and undervoltage transients

   (b) **Name of the author:**Sasa Z. Djokic Jovica V. Milanovic, Senior Member, IEEE, and Daniel S. Kirschen, Senior Member, IEEE

   (c) **Journal:**IEEE transactions on power delivery, vol.19, No.3, July 2004

   (d) **Summary:**This paper discusses the sensitivity of ac coil contactors to voltage sags, short interruptions and undervoltage transients on the basis of the results of the following tests: sensitivity to rectangular voltage sags with ideal and nonideal supply voltage, testing with two stage voltage sags, voltage sags which occur during starting of large motors, and also against the measured voltage sag. All contactors are tested without load attached to their main electrical contacts. These normally open main contacts are used to get a clear identification of the disengagement of the contactor. In testing, the nominal voltage is applied to the ac coil of the contactor before and after the voltage sag. If the sag causes disengagement of the contactor it surely indicates a malfunction of contactor.

6. (a) **Name of the chapter:**Sensitivity of personal computers to voltage sags and short interruptions
   (b) **Name of the author:**S. Z. Djokic, J.Desmet, member, IEEE G. Vanalme, J.V.Milanovic, senior member, IEEE, and K.Stockman, student member, IEEE
   (c) **Journal:**IEEE transactions on power delivery, vol.20, No.1, January 2005
   (d) **Summary:**This paper discusses the sensitivity of personal computers (PCs) to voltage sags, short interruptions on the basis of the results of the following tests: sensitivity to rectangular voltage sags with ideal and nonideal supply voltage, testing with two stage voltage sags, voltage sags which occur during starting of large motors. During the testing, a rated voltage (having ideal or non-ideal supply characteristics) was applied to the PCs before and after the voltage sag. The following malfunctions are identified (i) corruption or interruption of read/write drive. (ii) Frozen screen and lack of response to any command. (iii) hardware malfunction.

7. (a) **Name of the chapter:**Sensitivity of Adjustable speed drives (ASDs) to voltage sags and short interruptions
   (b) **Name of the author:**S. Z. Djokic, K. Stockman, member, IEEE, J.V.Milanovic, senior member, IEEE, J. J. M. Desmet, member, IEEE and R. Belmans, senior member, IEEE
   (c) **Journal:**IEEE transactions on power delivery, vol.20, No.1, January 2005

(d) **Summary:**This paper discusses the sensitivity of personal computers (PCs) to voltage sags, short interruptions on the basis of the results of the following tests: sensitivity to rectangular three phase, two phase and single-phase voltage sags with ideal and non-ideal supply characteristics, as well as sensitivity to nonrectangular balanced three phase voltage sags similar to those caused by starting of large motors.

8. (a) **Name of the chapter:**Probabilistic assessment of equipment trips due to voltage sags

   (b) **Name of the author:**C.P.Gupta, member, IEEE, J.V.Milanovic, senior member, IEEE

   (c) **Journal:**IEEE transactions on power delivery, vol.21, No.2, April 2006

   (d) **Summary:**This paper discusses the uncertainty involved in the behavior of sensitive equipment used in various industrial processes and methodology to incorporate this effect in quantifying the equipment trips due to voltage sags over a specified time period. For the stochastic assessment of equipment trips due to voltage sags the following four different probable behaviors were considered within their ranges:- (i) Uniform Sensitivity- If there is an equal probability that the equipment voltage tolerance curve may assume any location within the region of uncertainty, it can be represented by assuming fx(T) and fy(V) to be uniform probability density functions for Tand V within their respective range. (ii) Moderate Sensitivity- This type of sensitivity can be expressed by assuming fx(T) and fy(V) to be normal probability density functions. (iii) High Sensitivity- If probabilities are assumed in exponentially decreasing order from high-voltage threshold to low-voltage threshold and from low duration threshold to high duration threshold. (iv) Low SensitivityExponential distribution assumed to be opposite of the previous case. After calculating the joint probability density functions, expected number of trips of a particular equipment can be calculated

9. (a) **Name of the chapter:**Probabilistic assessment of financial losses due to interruptions and voltage sags-part I: The methodology

   (b) **Name of the author:**J.V.Milanovic, senior member, IEEE C.P.Gupta, member, IEEE

   (c) **Journal:**IEEE transactions on power delivery, vol.21, No.2, April 2006

   (d) **Summary:**This paper provides a generalized methodology for the stochastic assessment of the financial losses due to interruptions and voltage sags. The methodology proposed takes into account all the uncertainties in a probabilistic manner associated with the voltage sag calculation, sensitivity of customers equipment to voltage sags, the interconnection of the equipment within an industrial process, and customer types and the location of the process in the network. For an economic assessment of financial losses due to voltages sags, it is a prerequisite to have the information about the type of industrial/commercial process, customer type, and the associated damage cost per sag event. Some of the customers quote very high cost for the single trip, whereas for others, it might not be that substantial. Finally, the total costs incurred due to voltage sags and interruptions should be added together in order to come up with total network financial losses for a given network topology

10. (a) **Name of the chapter:**Probabilistic assessment of financial losses due to interruptions and voltage sags-part II: practical implementation

    (b) Nameof the author:J.V.Milanovic, senior member, IEEE C.P.Gupta, member, IEEE

(c) **Journal:**IEEE transactions on power delivery, vol.21, No.2, April 2006

(d) Summary:The second part of this paper presents a practical implementation and application of the methodology for the stochastic assessment of the annual financial losses due to interruptions and voltage sags discussed in the first part of this paper. The methodology is illustrated on a generic realistic distribution network with all relevant network components modeled appropriately. Finally, different network topologies are compared taking into account total financial losses in the network.

11. (a) Name of the chapter:Analysis of voltage tolerance of AC adjustable-speed drives for three phase balanced and unbalanced sags

(b) Name of the author:Math H.J.Bollen, senior member, IEEE, Lidong D. Zhang

(c) Journal:IEEE transactions on industry applications, Vol.36, No.3, May/June 2000

(d) Summary:This paper analyses the behavior of three phase ac adjustable speed drives, equipment most sensitive to voltage sags, during balanced and unbalanced sags. The conclusion from the analysis is that voltage sags due to three-phase faults are a serious problem for adjustablespeed drives. However, single-phase and phase-tophase faults, causing the majority of voltage sags, can be tolerated by adding a relatively small amount of dc-bus capacitance. It was shown that the drive behavior during an unbalanced sag is completely different from the behavior during a balanced sag. It was also shown that the sag type and the characteristic magnitude are the main affecting factors for the drive behavior, with the PN factor being important in a limited number of cases.

12. (a) Name of the chapter:Severity indices for assessment of equipment sensitivity to voltage sags and short interruptions

    (b) Name of the author:J.Y. Chan, Student Member, IEEE, J. V. Milanovi, Senior Member, IEEE

    (c) Journal:IEEE 2007

    (d) Summary:The paper proposes new indices to assess the impact of voltage sags and short interruptions on industrial equipment. The indices translate physical sag parameters into terms that reflect the severity of the disturbances as seen by the equipment. Using these indices, the uncertainties involved in equipment tolerance are addressed through proper event categorization and a common platform developed for the evaluation of equipment ride through capability with respect to voltage sags and short interruptions. The paper introduces Magnitude Severity Index (MSI), Duration Severity Index (DSI) and combined Magnitude Duration Severity Index (MDSI) and Categorizes voltage sags based on these indices. Finally, it also illustrates procedures to convert physical sag parameters (sag magnitude and duration) into severity indices on programmable logic controllers (PLC), personal computers (PC), adjustable speed drives (ASD) and AC contactors.

chapter 2

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References