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# Analysis of AC Contactor Model during Voltage Sag with Point-in-Wave of Initiation

***Abstract**. This paper presents the analysis of AC contactor model, its ride through capability and behaviour during voltage sag with point-in-wave of initiation using PSCAD/EMTDC simulation software. The ride-through capability curve is used to identify the sensitivity level in the AC contactor failure area. AC contactor simulation model were supplied with various type of voltage sag with point-in-wave of initiation. Simulation results are also validated with the ride through capability curve of the experimental results.*

***Streszczenie.** Przedstawiono analizę pracy stycznika AC podczas możliwych zapadów napięcia przy wykorzystaniu symulacji z PSCAD/EMTDC. Modelowano różne stany zapadów jak też i różne pozycje stycznika. (**Analiza modelu stycznika AC podczas zapadu napięcia**)*

**Keywords:** AC contactor, ride through capability, voltage sag, point-in-wave.
**Słowa kluczowe:** stycznik AC, zapady napięcia.

## Introduction

AC contactor is an electromechanical device, widely used in the industrial process for making/breaking contacts of the load circuit for controlling the equipment such as motor, heater etc [1]. These AC contactors are the most sensitive equipments to power quality problems, especially in voltage sags [2-4]. When AC contactor face voltage sag problem, industrial process control may shutdown and can be a large cost to the business [5-7]. Thus, it is important to understand the sensitivity of AC contactor to predict their behavior during voltage sags. The factors which influence the behavior of the AC contactor during voltage sag cannot be explained by magnitude and duration alone [8]. However, magnitude, duration and point-in wave where sag occurs are very important aspect in describing the performance of AC contactor [9]. Although many researchers have been investigated the behaviors of the equipments due to the voltage sag, however, only few studies have investigated on point-in-wave performance on AC contactor [10]. The IEEE STD 1346-1998 recommends that the point-in-wave and phase angle jump should not be considered in low voltage equipment [11]. However, in greater voltage sag, the magnitude, duration, point-in-wave and phase angle jump are considered to investigate the behavior of AC contactors [12]. Different contactors were tested for different characteristics of voltage sag during the large motor start up. It is seen that in case of bigger voltage magnitude drop the contactor becomes more sensitive to point-in wave of sag initiation. For shorter voltage sag, the 90° sensitivity curve is most restrictive and the 0° curve is the least restrictive with respect to contactor ride through capacity [13-14]. Many research works have been published on the investigation of AC contactor behaviour under different characteristics of voltage sag [15-18]. However, a few works has been reported on the effective methods to improve voltage sag ride through capability.

## AC Contactor Model

In order to determine the behavior of the AC contactor, to simulate variety of its characteristics, the contactor model is taken into account on mathematical models. In electromechanical system of a simplified AC contactor model, the attraction force between armature and the frame can be expressed as follows [1].

1. $$F = \frac{\partial W}{\partial x} = -\frac{1}{2}\phi^2 \frac{\partial \Re}{\partial x}$$

where $W$ is the magnetic energy, $\phi$ is the instantaneous flux in the contactor, $\Re$ is the total reluctance involved and x is the gap distance in meters. In addition, an expression for the reluctance can be written as:

2. $$\Re = \frac{l}{\mu_r \mu_0 A} + \frac{2x}{\mu_0 A}$$

where $l$ is the mean path of the flux in the core, μr is the relative permeability of the magnetic material, $\mu_0$ is the absolute permeability of the free space and A is the cross sectional area of the air gap.

Thus, the instantaneous magnetic force that tends to close the air gap in the contactor can be expressed from (1) and (2) as follows:

3. $$F_M = \frac{\phi^2}{2\mu_0 A}$$

The instantaneous flux can be expressed by

4. $$\phi = \frac{NI}{l/\mu_r \mu_0 A}\cos(wt)$$

where, $N$ is the number of coil turn and $I$ is the amount of current flow through coil.

The normal AC contactor can be shaded or unshaded ring for it application. The resulting current generates a reaction flux that lags the main flux. Thus, the main flux is the combination of shaded, $\phi_s$ and unshaded, $\phi_u$ flux. Then, the magnetic force in the contactor can be expressed as follows:

5. $$F_M = \frac{\phi_s^2}{2\mu_0 A_s}\cos(wt-\alpha) + \frac{\phi_u^2}{2\mu_0 A_u}\cos(wt+\beta)$$

where $A_u$ and $A_s$ are the cross sectional area of unshaded and shaded poles, respectively. $\alpha$ and $\beta$ are the phase shift angles, respectively.

AC contactor acts as a switch depending on the coil impedance and electrical contact. Electrical contact is open/close based on the current supplied to the coil which generates the flux and magnetic force. AC contactor model is developed using mathematical model as mentioned in (1) to (5). Thus, the algorithmic flowchart of AC contactor model is constructed as shown in Fig. 1, where cosine square of shaded and unshaded pole angle need to be incorporated.

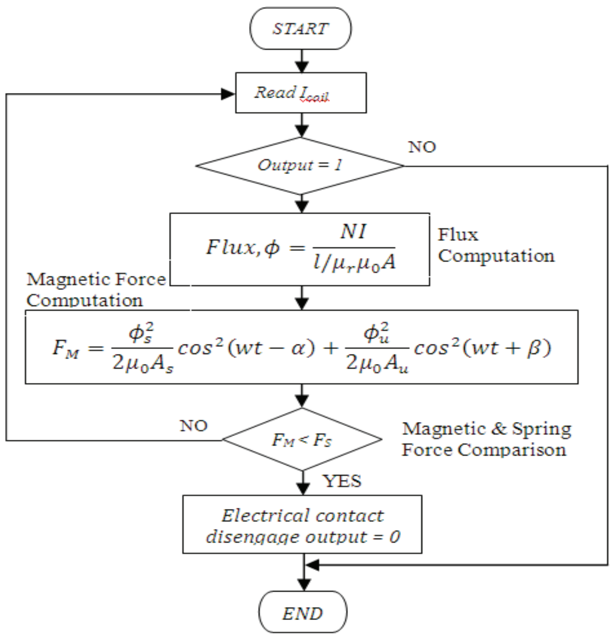


Fig. 1. AC contactor algorithmic flowchart

**Methodology**

PSCAD/EMTDC is used to develop sag generator and AC contactor simulation models for supplying voltage sag with different sag magnitude, duration and point-in-wave. The voltage sag characteristics are controlled by the generator parameters such as voltage source, percentage of nominal voltage, time to apply sag, duration of sag and point-in-wave in sag configuration controller. The AC contactor simulation model is developed based on the mathematical model as shown in Fig. 1.

The sag generator supplies current to the AC contactor simulation circuit as shown in Figure 2. The voltage sag configuration is set at 40 % of the nominal voltage, occurred at 0.1 s with duration of 0.1 s and point-in-wave is $90^0$, respectively as shown in Figure 3 (a). The rms value of contactor coil current is changed accordingly as shown in Figure 3 (b) as well.

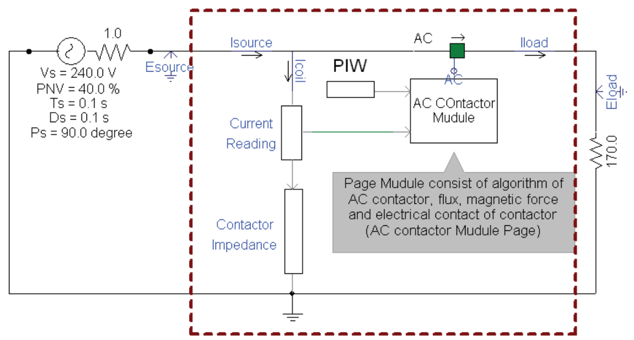


Fig. 2. AC contactor simulation circuit in PSCAD/EMTDC

The electrical AC contactor status and load current signal are shown in Figure 4. It is seen that when the contactor status is 0, the switch is in closed contact providing current waveform as shown in Figure 4(b). Again, switch at open contact i.e. 1, the output current is tends to 0 i.e. disengage. Once the contactor disengaged, it will remain unchanged even when the sag recover to the nominal voltage. The contactor will only engage when it is switch on manually. Thus, it is concluded that at voltage sag condition, the contactor is disengaged due to open electrical contact of the contactor model.

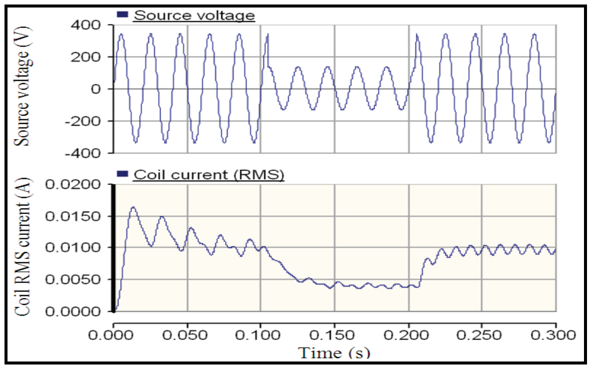


Fig. 3. AC contactor signal a) source voltage b) rms coil current

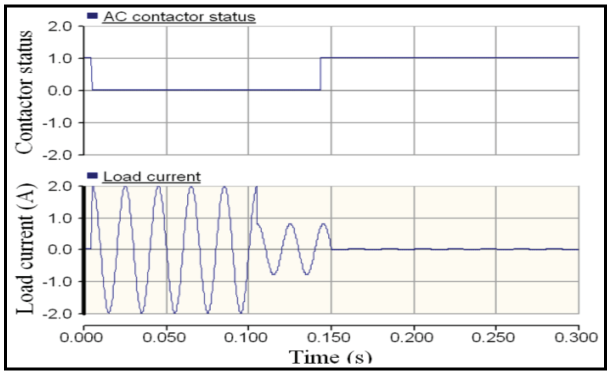


Fig. 4. AC Contactor status and load current signal

**Results and Discussions**

The AC contactor sensitivity and dynamic behavior were examined and discussed through simulation modeling. Ride-through capability and the sensitivity of the AC contactor simulation modeling was done by PSCAD/EMTDC software. The results findings from the model on sensitivity of AC contactor during voltage sags with point-in-wave of initiation are presented as typical voltage tolerance curves. The upper region of these curves represents normal operation region while the lower region indicates unacceptable voltage conditions for AC contactor operation i.e. fail area. The voltage tolerance curves were introduced to represent the performance of AC contactor behavior and its sensitivity for various voltage sag configuration under different point-in wave. Figure 5 shows the simulation results of the ride-through capability curve under $0^0$, $30^0$, $60^0$ and $90^0$ point-in-wave of initiation for representation of contactor sensitivity i.e. so called voltage-tolerance curve of the contactor. These curves are illustrating the contactor response to voltage sags with a particular magnitude and duration. The ride-through capability curve of the AC contactor divides into two areas between duration-magnitude plane, showing which voltage results in normal operation and which voltage sag is in mal-function or failure. For example, at $90^0$ point-in-wave of initiation, 57.5% voltage sag down is in normal operation i.e. the contactor can survive up to 57.5 % of voltage sag and below 57.5 % of voltage sag is in mal-function area i.e. contactor is failed. It is noted that the instant sag initiation determine the duration of voltage sag as approximately 1/8 cycle. At $0^0$ point-in-wave of initiation, AC contactor can survive up to 42.5 % of voltage sag and the duration of voltage sag approximately 3 cycles. Similarly, at $30^0$ and $60^0$ point-in-wave of initiation, AC contactor start to fail when voltage sags are above 55 % and 53 % of nominal voltage with duration of 2 cycle, respectively.

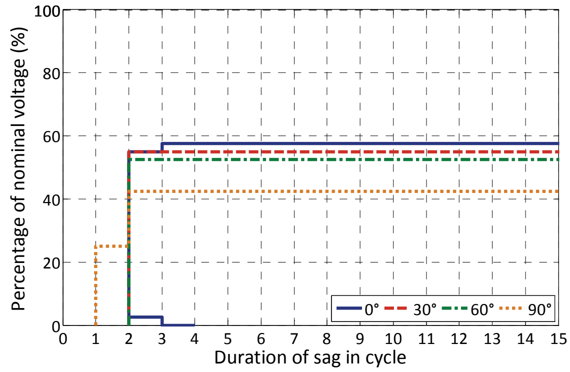


Fig. 5. Simulation model voltage tolerance curves at $0^0$,$30^0$,$60^0$ and $90^0$ point-in-wave of initiation angles

The ride-through capability curves of simulation were compared with the experimental result, Fig. 6 to validate the AC contactor model that is built in PSCAD simulator. The results obtained from the comparison observed that the ride-through capability curve for AC contactor constructed from the simulation results are identical with the results accumulate from the experimental. The sensitivity of the AC contactor could be assessed by both ride-through curve that the higher the point-in-wave of initiation, higher the voltage sag survival and lower the duration voltage sag. Thus, it can be concluded that the point-in-wave of initiation has dominant influence on contactor sensitivity.

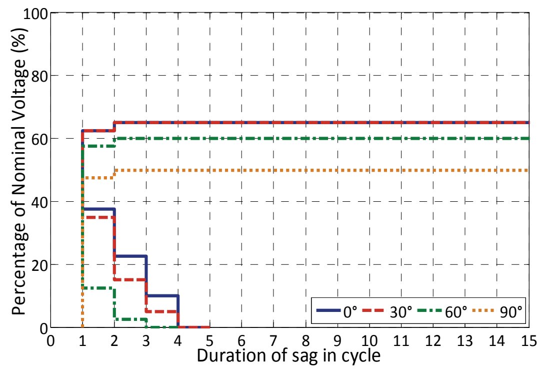


Fig. 6. Experimental voltage tolerance curves at $0^0$,$30^0$,$60^0$ and $90^0$ point-in-wave of initiation angles

## Conclusion

This paper describes the development of AC contactor simulation model for evaluating its sensitivity during voltage sags. The simulation results demonstrated the performance of the voltage sensitivity level of the AC contactor during voltage sags with varying point-in-wave initiation. It is observed that the sensitivity level of the AC contactor is exhibited in its voltage tolerance curves which predict the behaviour and the failure area of the contactor. From the voltage tolerance curves of the AC contactor, it can be concluded that the higher the point-in-wave of initiation, the better will be the ride through capability of the AC contactor.

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