THE BEHAVIOUR OF CONTACTORS DURING VOLTAGE DIPS

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SYNOPSIS

Electrically held-in contactors may drop out during voltage depressions. The time that contactors take to drop out depends on the current that flows in the coil at the moment of a voltage dip and where in the cycle the voltage dip occurs. This article endeavors to report on investigations done into the behaviour of contactors when subjected to voltage dips.

1. INTRODUCTION

The purpose of contactors is to control large currents and voltages with small control currents and voltages and to facilitate remote control. Typical examples would be the control of a large three phase motor or an electric furnace.

Some of the problems facing modern industry are voltage dips occurring in the electrical supply. The voltage dips can cause electrically held-in contactors to drop out. To make provision for this, it is important to know how a contactor functions, why it drops out and how long it takes to drop out, under different circumstances. In the following, we will try to find answers to these questions. Special emphasis will be placed on AC contactors, as this type of contactor is more susceptible to voltage dips than others.

2. CONTACTOR OPERATION.

To understand contactor behaviour their operation must be understood. Fig 1 describes the function of a contactor in a simplified way.

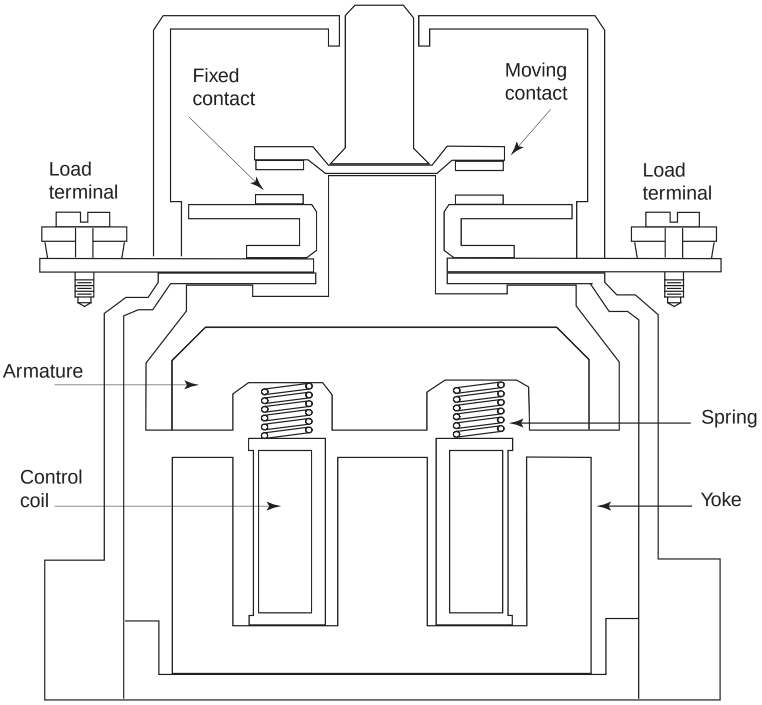

Fig 1

Functional diagram of a typical contactor.

A typical contactor consists of three basic parts :-

1. The control coil

2. The magnetic circuit and
3. The spring loaded mechanical link that controls the contacts with the the contact arrangement.

The magnetic circuit consists of two parts, the armature which has the coil wound around it and is stationary and the yoke which is pushed away from the armature by springs and can move to close the magnetic circuit. The yoke is mechanically linked to a contact arrangement, typically three normally open power contacts and a number of N/0 or N/C auxiliary contacts. A current in the control coil induces a magnetic field that flows through the armature, the yoke and the two air gaps between the armature and the yoke. The field tries to reduce the air gap by producing a strong attractive force, if this force is stronger than the spring pressure that pushes the yoke away from the armature the yoke will move to close the air gap. The mechanical link in turn will operate the contact arrangement.

A typical circuit diagram is shown in Fig 2.The reluctance of the magnetic circuit is much less with an air gap present than with the gap closed. The current in the coil is therefor at first rather large and decreases dramatically when the contactor closes. The relationship of inrush VA and holding VA is shown in Table 1 for different sizes of contactors. The drop off voltage expressed as a percentage of the nominal voltage is also shown.

Contactor size	**Energising VA cosΦ**	**Holding VA cosΦ**	**Drop off voltage**
Small (<50A)	70 0.8	10 0.29	53%
Medium (50-200A)	350 0.5	45 0.15	68%
Large (>200A)	1750 0.5	125 0.1	65%

Table 1

Comparison between pull in & holding VA.

A contactor drops out when the field strength of the magnetic field becomes smaller then spring pressure that tries to push the yoke away from the armature. This happens when the voltage falls to between 50% and 70% of nominal voltage.

3. CONNECTING CONTACTORS IN A CIRCUIT.

Contactors are used where large currents and voltages must be controlled either locally or remotely, see Fig 2.

By pushing the Start button (N/0) voltage is connected to the coil. The contactor and its auxiliary contacts are pulled in and current can flow via the normally open bridging contact after the Start button is released. The Stop button (N/C) interrupts the circuit when pressed, the contactor drops out and stays out after the Stop button is released because the bridging contact has opened as well.

4. TEST CONDITIONS TO DETERMINE DROP OUT TIMES.

Contactors are tested under various conditions, namely

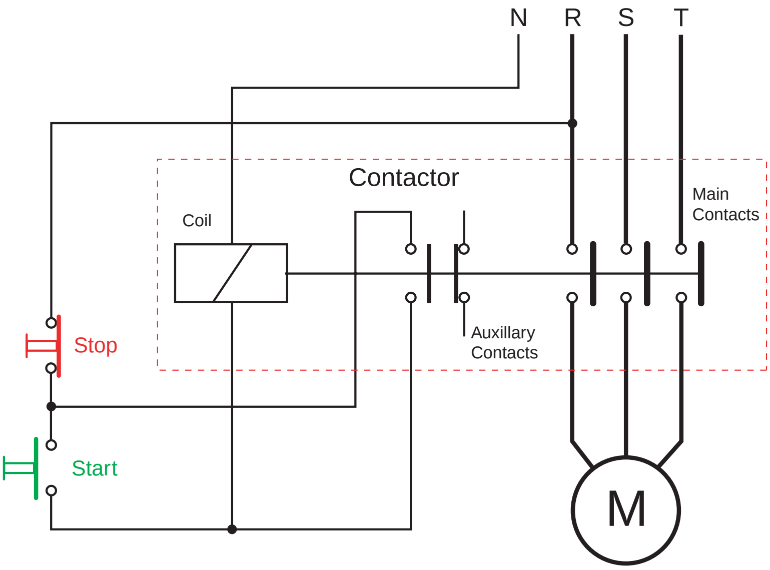

Fig 2

Typical contactor connection diagram.

- A short circuit of the network in the vicinity of the contactor (single or 3 phase faults).
- An open circuit in the supply eg. a circuit breaker that opens and then automatically closes again and
- A remote short circuit on a transmission-line that only cause partial voltage drops.

To simulate these conditions, it was necessary to use a special time control switch to accurately determine the drop out time of the contactors. In Fig 3 an example of the test conditions is given.

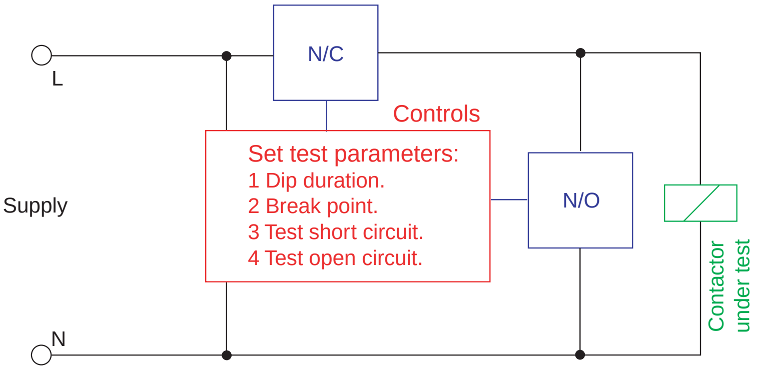

Fig 3

Test setup to measure the drop out time of contactor.

The duration of the voltage dip can be set in steps of 1ms. The position on the sine wave where the voltage drop begins, can also be set in steps of 1ms. An example is shown in Fig 4. Short circuits and open circuits can also be simulated.

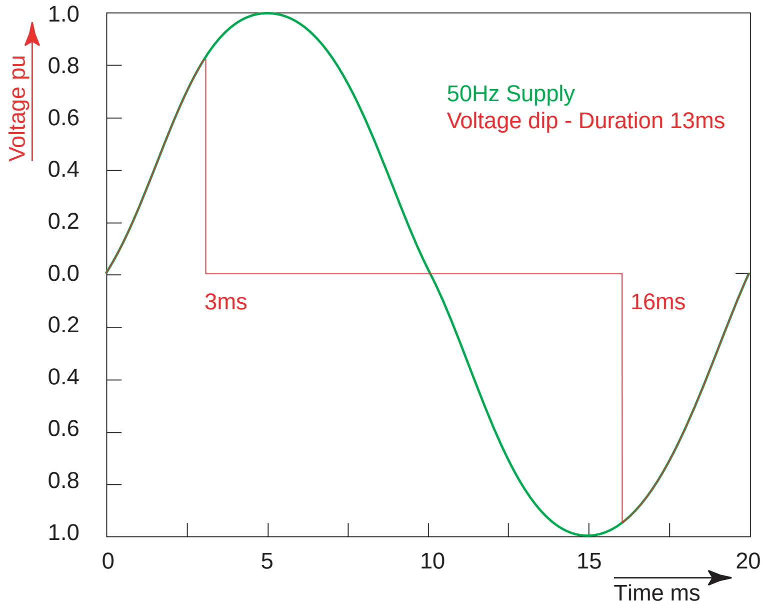

Fig 4

Example of a waveform generated by the simulator.

The voltage dip begins 3ms after zero crossing and persists for 13ms.

5. RESULTS FOR DIFFERENT CONTACTORS' DROP OUT TIMES

A large variety of contactors of different manufacturers where tested. The contactors where divided according to continuous current ratings into 3 classes, namely

- light current (smaller than *50A),*
- medium current (between 50A and 200A)
- heavy current (greater than 200A).

Figs 5 to 7 show the results of the tests done on small medium and large contactors. Three waveforms are shown, a normalized voltage waveform and drop off delays for open circuits and short circuits. The drop off times vary with the phase angle at which the dip occur.

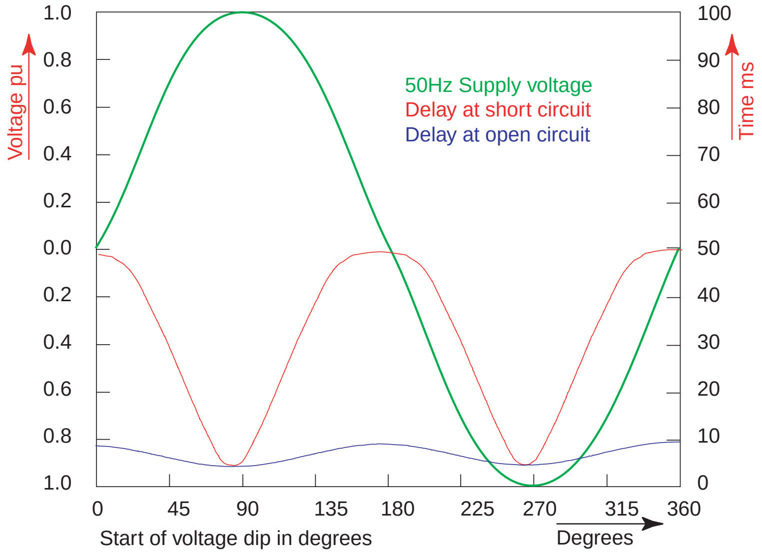

Fig 5

Drop off delays for a small contactor.

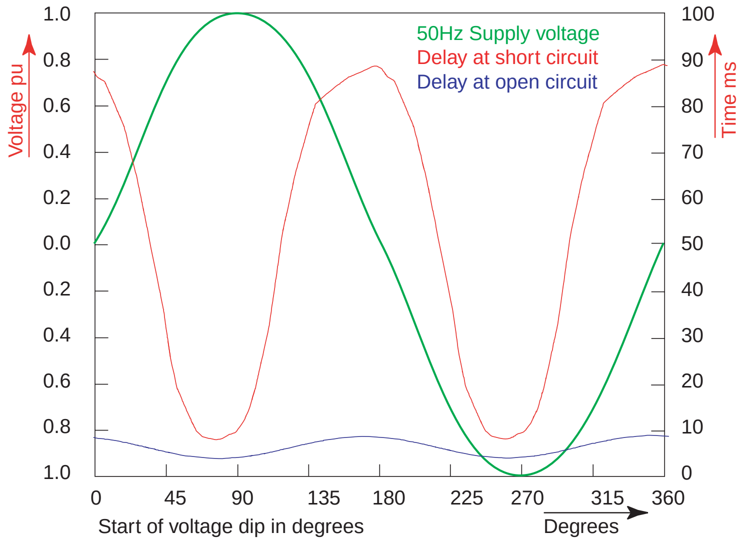

Fig 6

Drop off delays for a medium sized contactor.

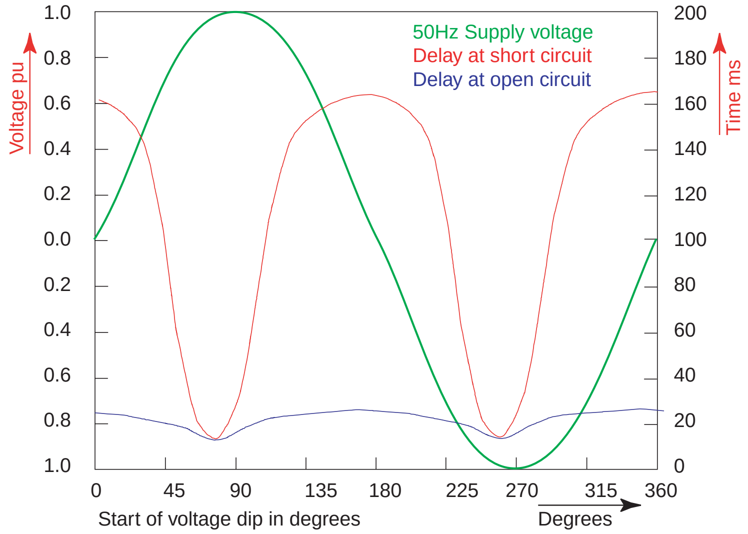

Fig 7

Drop off delays for a large contactor.

The result in Fig 8 is of an AC contactor with half wave rectified sine wave applied to it.

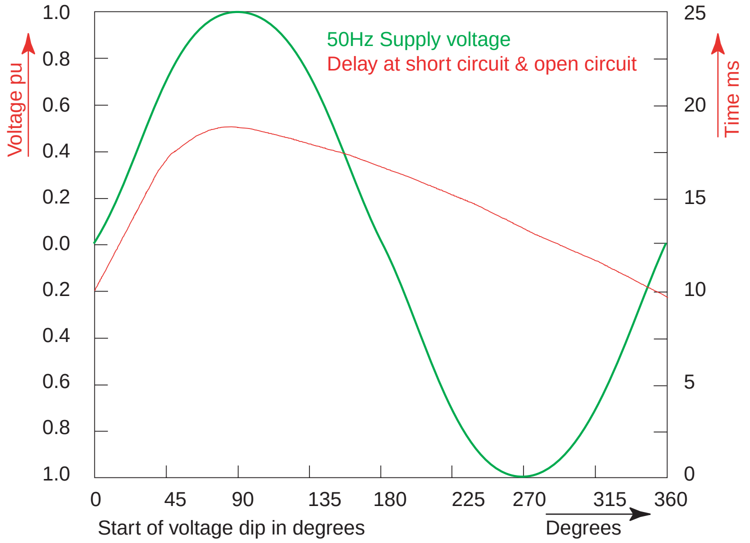

Fig 8

Drop off delays for a contactor with half wave rectified supply on the coil.

5.2 INFLUENCE OF THE VOLTAGE DIP MAGNITUDE.

To simulate faults that occur relatively far from the contactors, the circuit in Fig 9 was used. In this example the voltage is dropped to 75% and 50% of nominal voltage and the drop-out time of the contactors is monitored. All sizes of contactors reacted more or less the same, we therefor show only one diagram.

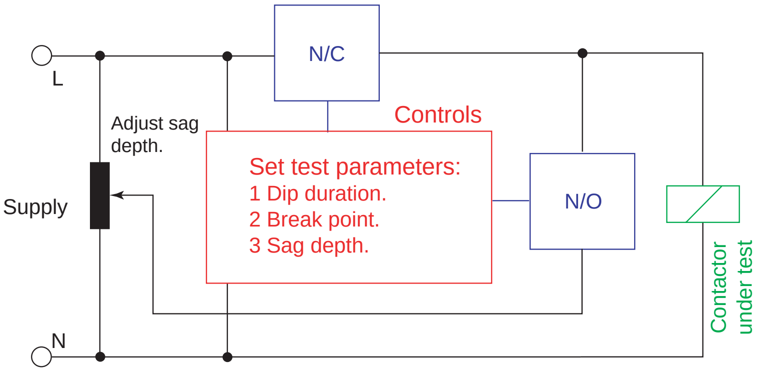

Fig 9

Circuit for generating voltage dips of varying magnitude.

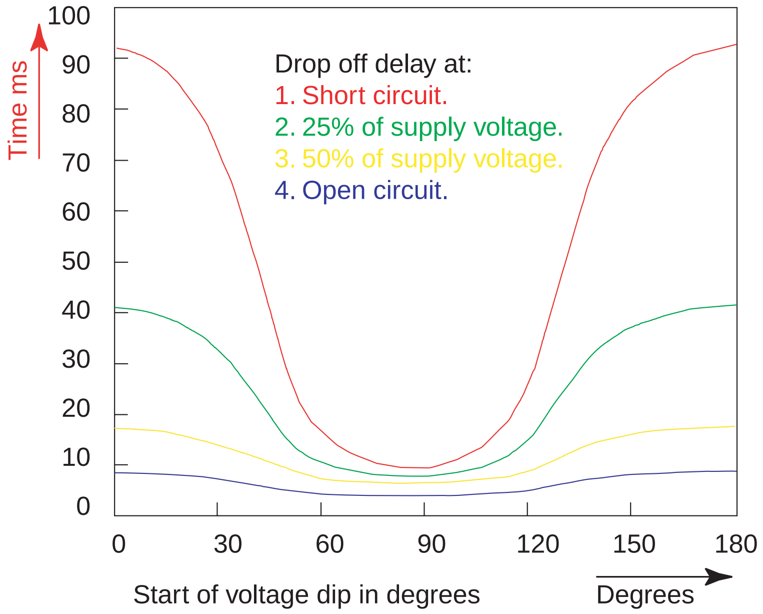

Fig 10

Delay times for voltage drops of varying magnitude.

6. DISCUSSION OF RESULTS

6 .1 DROP OFF TIME.

It becomes clear from the results in paragraph 5 that the drop off time is shortest when the coil voltage is near its peak value and longest at zero crossing. Coils of contactors are highly inductive loads, that means that the current is lagging the voltage. The powerfactor of energised contactors is between 0.1 and 0.3 which represents a lagging phase angle of 72° to 85°. The attractive force that keeps the yoke and the armature together is proportional to the square of the field strength of the magnetic field, which is in turn direct proportional to the current flowing in the contactor coil. This means that at each zero crossing of the current the contactor begins to drop out. Shortly afterwards the current and with it the magnetic field begins to build up again and the contactor is reclosed. This action makes the contactor chatter. To avoid this an alternative current path in the form of a split pole is introduced, this is a copper ring that encompasses part of the cross area of the magnetic field and is situated near the air gap. The eddy current induced in the copper conductor has the effect of providing a magnetic field while the main magnetic field is at zero level, chattering is avoided but the drop off time of the contactor is also retarded. This and the inherent sluggishness of the mechanical parts of the contactor explain the minimum drop off time. Maximum drop off time coincides with the maximum current in the coil, the total field is larger and takes longer to dissipate in the split pole conductor.

6.2 SHORT CIRCUIT vs OPEN CIRCUIT

A significant difference in drop off time can be detected between open circuiting the contactor coil and short circuiting it. In the case of open circuit, the only device that provides some current path is the split pole winding which is very inefficient firstly because the ampere winding product is small and secondly the single winding covers only part of the total flux. In case of a short, the coil acts as the induction path, the coupling is much better and the ampere turn product is much higher which makes the current small, the losses are much smaller therefor the magnetic field collapses much slower.

6.3 RECTIFIED AC ON CONTACTORS

From Fig 8 can be seen that there is no difference in the drop-out time for short circuit and open circuit conditions. The reason for this lies in the fact that the alternating current is first halfwave rectified see Fig 11. This phenomena can be simulated by the use of a single diode and a capacitor. A capacitor filter stores the energy and thus reduces output voltage ripple. In the event of a voltage drop, all the energy stored in the capacitor is discharged through the coil. Current therefor still flows in the circuit irrespective of whether the supply network is in an open or short circuit condition. The time taken for the contactor to drop out is directly proportional to the amount of energy stored in the capacitor.

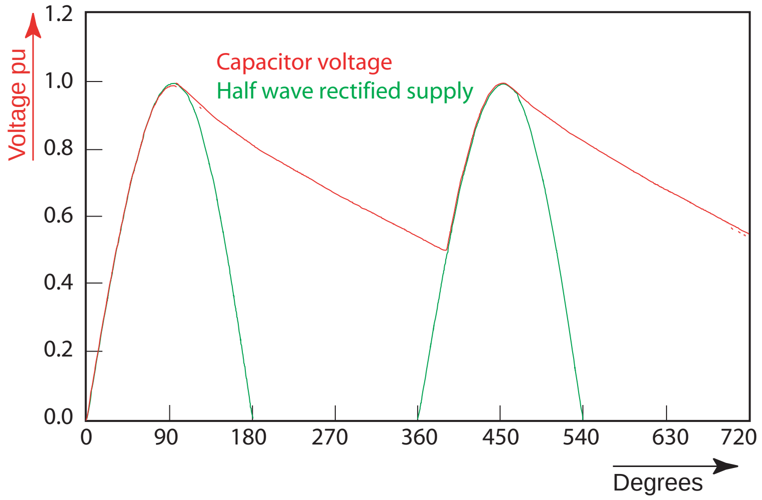

Fig 11

Half wave rectified voltage with a small capacitor on the diode output.

A further important deviation that may be observed is that the maximum drop out time appears at maximum voltage. This is due to the fact that the capacitor largely reduces the inductive action of the coil and thus tends to form a resistive load. This means that the magnetic field is strongest when the voltage is at its maximum and therefor the contactor takes longer to drop out. Subsequently the contactor has the shortest dropout time when the voltage is at its minimum.

6.4 DEPTH OF VOLTAGE DIP

Here results are in total contradiction with what one would initially expect. The larger the voltage drop the longer the contactor takes to drop out. The reason for this is almost the same as the difference between open and short circuit conditions. When the control coil terminals are shorted the contactor takes relatively long to drop out while no voltage appears across the terminals. For the voltage to drop away totally, there needs to be a very low resistance fault close to the contactor. As the fault resistance increases the voltage across the control coil terminals also increases. As the fault resistance increases larger portions of the energy stored in the coil are lost in this fault circuit. As resistance increases, the losses increase and subsequently the contactor drops out faster. Here the minimum dropout time will be reached when a voltage drop appears that is just not enough to hold the contactor in.

7. CONCLUSION

All contactors that are electrically held in are sensitive to voltage dips. Contactors are very sensitive to where in the voltage cycle the dip starts. The dropout time also depends on the type of fault in the system. An open circuit condition causes contactors to drop out significantly faster than under short circuit conditions. Furthermore large voltage drops cause contactors to be held in longer than when the voltage drop is small. Any significant voltage drop longer than 3ms can start contactor dropout.

In order to prevent contactor dropout the fault must be removed within 3ms or an alternative supply must be connected within 3ms. Normal prevention and switchover techniques take far longer than 3ms to restore supply currents and therefor contactors drop out, often with large financial implications. To solve this problem one must look for an alternative to AC contactors or systems that are capable of restoring power within 3ms after the voltage dip starts.

Paper:The behaviour of contactors during voltage dips

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