Mitigating the effect of voltage sags on contactors in industrial plant and substations

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In this article the difference between electrical equipment in manufacturing plants and that in electrical power substations is discussed. Theses differences dictate two different sets of requirements for supplying power to large AC contactors. The article offers two technical solutions: one of which is based on the contactor remaining in the closed position at voltage sag; and the second is based on the instantaneous switching-off of the contactor at voltage sag with a subsequent switching-on with time delay.

According to IEC 61000-4 [1, 2] voltage sags are brief reductions in voltage, lasting from tens of milliseconds to 15 s (see Fig. 1). The main cause of voltage sags in the 400 V network of the substation auxiliary supplies is short circuits in external high voltage grids. In manufacturing plants such voltage sags are frequently associated with the working modes of high power electrical equipment, e.g. start-up of motors. Voltage sags are an important criterion of the power quality.

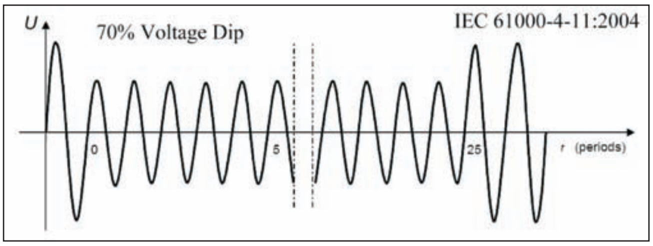

Fig. 1: Example (from IEC 61000-4-11) of a 70% voltage sag duration of 25 cycles.

Voltage sags in 400 V networks in manufacturing plants

Sags in the 400 V networks of manufacturing plants may seriously disturb the production cycle due to mass disconnection of electrical motors during the sag, followed by auto-starting of motors, which may cause additional drops in voltage level and exacerbate the problem [3, 4].

As shown in [5] upon power interruption to a motor of 0,4 – 0,8 s, the vectors of the residual electromotive force of the motor can occur in anti-phase with the vector of the network voltage. As a result, upon network voltage restoration, a high magnitude current pulse will flow through the motor, causing the tripping of the protective circuit breaker.

On the other hand, short voltage sags with durations of less than 200 - 300 ms (most frequent in 400 V network) do not harm the motors. For these reasons the means for ameliorating sags in networks in manufacturing plants have included technical solutions for keeping the contactors closed during sag, special dynamic voltage sag compensators, UPSs, etc. Because such compensators and high power UPSs are very expensive, different electronic devices [6, 7] have been developed that guarantee feeding the contactor's coil from a DC power supply during short sags.

In an AC contactor there is a considerable variation in current consumed by its coil during operation, leading to considerable variation in the core's attractive forces needed. When feeding a contactor's coil from a DC supply, such current variations will not be present and the contactor will not work properly.

These electronic devices use four levels of DC voltages for feeding the contactor coil, which simulates the natural attraction force characteristics at contactor pickups on AC. These electronic devices with integrated circuits (microchips) are not intended, however, for use with powerful contactors with low resistance coils (10 – 15 Ω) and high inrush currents. For example, the power consumed by the coil of the 3NTF54 contactor at pickup is 1,6 kVA on AC and 1,2 kW on DC (with a special starting coil).

For large contactors with powerful coils special devices have been developed which work on another principle, shown in Fig. 2. The device consists of undervoltage relay KU, timer K1 for an "Impulse-on" standard function, and a simple DC power supply consisting of transformer T, rectifier bridge VD2 and low voltage high capacity capacitor C. When control switch S1 is closed, the 230 V AC voltage is applied to the voltage relay KU which operates if the applied voltage is more than the minimum required (180 V in our case) and closes its contact in the feeding circuit of the KT timer, which instantly operates and connects the contactor's coil to the 230 V AC network through rectifier bridge VD1 and limiting resistor R1.

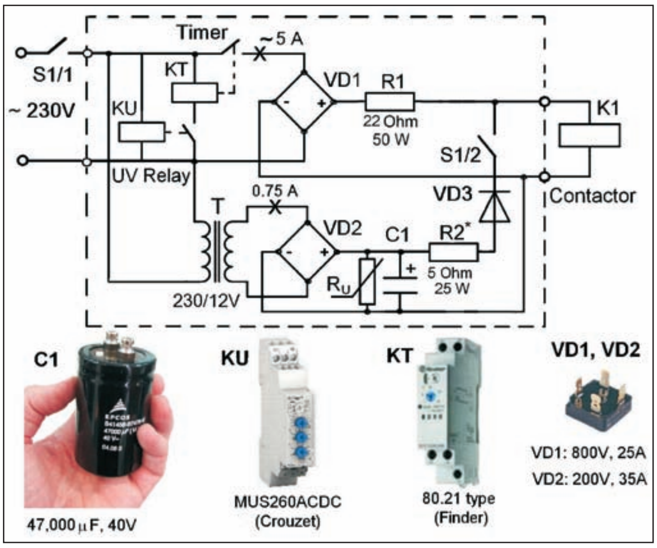

Fig. 2: Circuit diagram of the control device for high power AC contactor.

A direct current of approximately 5 A will be carried through the contactor's coil. Such current produces an electromagnetic force equivalent to that of the natural starting current leading to the connection of the contactor to the 230 V AC network. Simultaneously, capacitor C1 is quickly charged. Due to presence of diode VD3, capacitor C1 is charged from a low voltage (12 V) DC power supply and is completely isolated from the high voltage of approximately

70 V applied to the contactor's coil during start-up. After 2 - 3 s, the timer's contact breaks the high starting current in the contactor's coil. Diode VD3 will instantly unlock and the low-voltage power supply with the charged capacitor C1 will connect to the contactor's coil. The contactor's coil is fed by the lowered DC current, limited, in addition, by the low resistance resistor R2. Selection of the value of this resistor depends on the specific contactor type. For instance, for a 3TF54 type contactor, the resistance of this resistor has to be as low as 5 Ω. At this resistance the retention of the contactor in the closed position is provided over a long period of reduced AC voltage (down to 140 – 130 V) and, at the same time, the allowable temperature of the coil (50 - 60°) is not exceeded.

Research has shown that when feeding the contactor's coil with lowered DC current, its sensitivity to decreasing power supply voltage level is sharply reduced. For example, the contactor that was tested was held in the closed position at a voltage reduction on the coil from 12 V down to 2 - 3 V, that is in 4 - 6 times. This positive property is used in this device for holding the contactor for short-term downturns of the voltage level in AC networks. For very deep voltage sags or even full voltage loss, the energy of capacitor C1 holds the contactor operated. From the results of tests it appears that small size capacitors in the range of 47 000 μF at 40 V are capable of holding the contactor for periods of 1,3 - 1,5 s. This is quite sufficient for short-term voltage sags in real-life in AC networks. The rectifier bridge VD needs to be selected with considerable care because high current pulses flow through it during capacitor charging.

When the voltage in an AC network falls to a level lower than 160 V, the under-voltage relay KU opens its contact and disconnects the feeding circuit of the timer KT. The position of the output contact of the timer does not change, and the capacitor continues feeding the contactor's coil from the low-voltage DC power supply until the restoration of the proper voltage level in the AC network or, until the capacitor C1 energy is fully exhausted, at which time the contactor will be disconnected. With the restoration of network voltage to more than 180 V, the under-voltage relay KU again will pick up, timer feeding will be applied, and the working cycle of the device will repeat.

The "Impulse-ON" function, which is sometimes called "Interval", "Fleeting", "Single Shot", "Power ON", "Single Shot Leading Edge", "Rising Edge Pulse", represents the standard function. The timers actualizing such functions are widely available in the market. Unfortunately, only some from them are suitable for switching coils of large contactors. Using timers of the other types will necessitate using an addition auxiliary relay with powerful contacts inserted in circuit instead of the timer's contacts.

Voltage relay KU can be used as either an undervoltage relay with adjustable trip level or hysteresis, which do not require a separate power supply. The device is assembled in a closed plastic container with dimensions: 210 x 160 x 90 mm. It is abundantly clear that the device can be used with medium size contactors and as well as with small contactors. In both these cases the capacitance of the capacitor and the power of the transformer will dramatically decrease.

It needs to be noted that some manufacturers provide the possibility for feeding AC contactors from a DC power supply In this case the contactor's condition is fully independent of sags in the AC network. It offers one more way of solving the problem, but realising this solution is not simple because of special starting characteristic which need to be simulated as mentioned above. Two special windings for 3TF5 series contactors are available: a powerful operate winding (PW), and a low power holding winding (HW), shown in Fig. 3. Changeover from one winding to other after contactor K1 operates is effected with the help of an additional contactor, K2, connected in series with heavy contacts (for disconnection of the high inductive load at 230 VDC) and an additional auxiliary contact block (95, 96) on the main contactor.

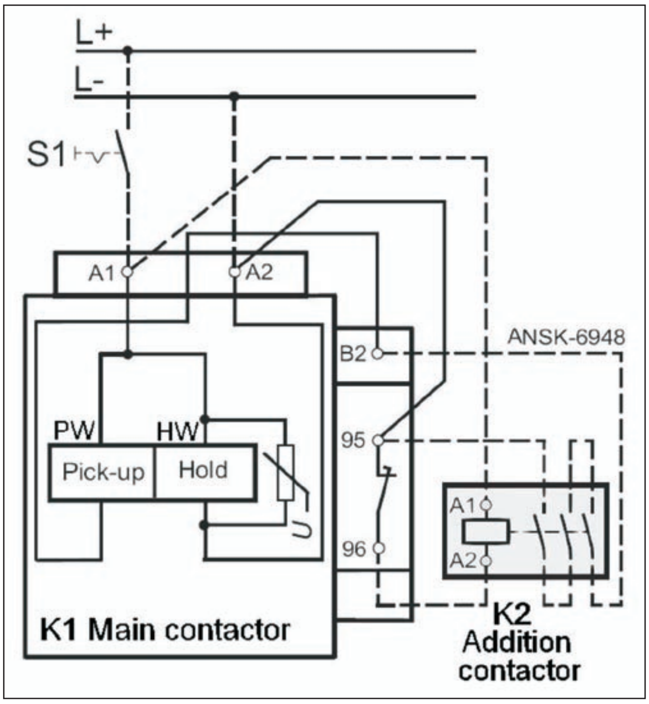

Fig. 3: CHECK WITH MIKE.

With the presence of a powerful battery and the possibility of setting the DC voltage to the contactor's location, the problem can be solved by means of a more intelligent method, such as the already mentioned timers and a small switching type power supply with an output voltage of 12 V and current 1,2 A, shown in Fig. 4. Only two cheap off-the-shelf devices are needed for realizing the solution.

Voltage sags in 400 V auxiliary AC networks in substations

The peculiarity of the low voltage auxiliary AC network in power substations is that it does not contain devices that tolerate short pauses in the power supply, and almost all of the critical auxiliary equipment is fed from the substation battery, while the power electronic systems with microprocessor controllers such as invertors,

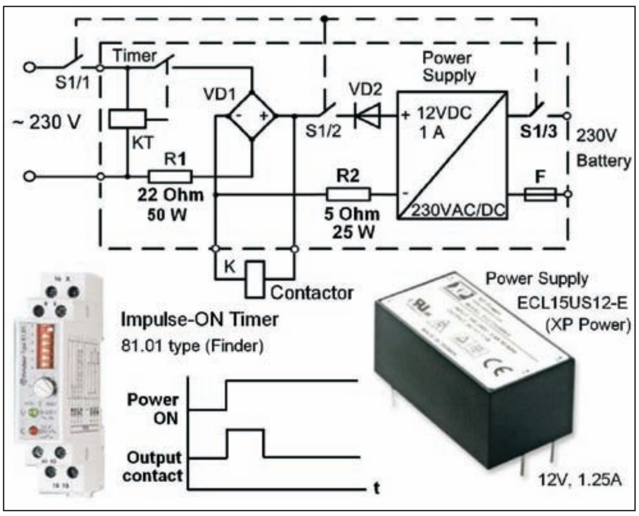

Fig. 4: Device for feeding a large AC contactor from a DC network with a large capacity battery.

battery chargers, and power supplies are fed from the auxiliary AC network. Experience has shown that such devices do not tolerate short voltage interruptions (50 – 200 ms), although they may have time to ride through automatic changeover from main to spare power supply (transformer). Another problem with battery chargers with large input transformers is the high inrush current at sudden interruption and subsequent input voltage restoration that causes full charger disconnection by the input circuit breaker. This state of affairs is considerably aggravated in some cases when even single voltage sags with durations of 100 – 200 ms provoke multiple operation and release of the contactor.

Problematic action of the contactors as changeover from main to reserved auxiliary AC power supply occurs

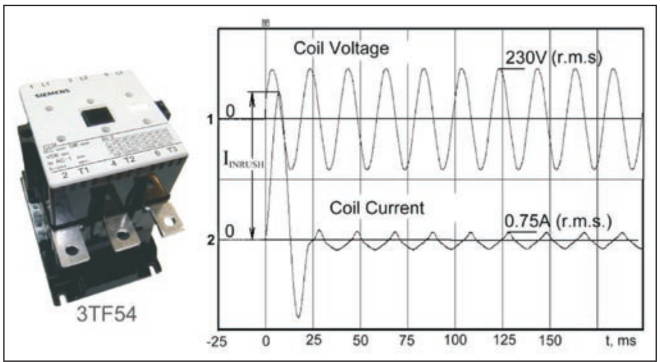

Fig. 5: Electromagnetic AC contactor 3TF54 type and oscillograms for current and voltage on its coil at switch-on.

To increase the reliability of the 400 V AC network in power substations two auxiliary transformers, fed from different lines, are normally used. One of them connects to the 400 V AC network permanently and the other one automatically connects at failure of the first transformer. Connecting and disconnecting the 400 V AC network to these transformers is affected by means of two contactors at currents of 200 – 400 A with AC control coils. These contactors are the major elements of the auxiliary network on which reliability of all substations depend.

As an example, contactor type 3TF54 with a switching capability of 300 A, which is commonly used as changeover in the auxiliary 400 V AC network in substations, was tested. See Fig. 5, Oscillograms of operation and releases of the contactor were recorded at the connection to the control coil from the AC supply, see Fig. 5 and 6. The oscillogram in Fig. 5 shows the presence of high starting (inrush) current caused by the low impedance of the coil until the moment of the closing of the contactor's magnetic circuit. Oscillograms shown in Fig. 6 allow determining the operate time and release time of the contactor, i.e., the reaction time of the contactor for voltage sags.

Analysis of the oscillograms shows that full switch-on time, t, is about 20 ms,and the full release time is 15 – 18 ms, compared to values given in the data sheet of 10 – 30 ms for nominal voltage applied before disconnection, and 10 – 15 ms for a voltage 0.8 of the nominal value. Such small time delays for large contactors means that during typical voltage disturbances with alternate voltage level sags and restorations, the contactor will have time to connect and disconnect the main power circuit several times. Moreover, as shown in [8], the reaction of the contactor during a 75% voltage sag is more serious than 100%, since the release time for first case is shorter by 40 – 50% than in second case and may be 10 ms even for large apparatus.

One more problem with the AC contactor was discovered during the research stage. It was found that reducing the voltage across the coil

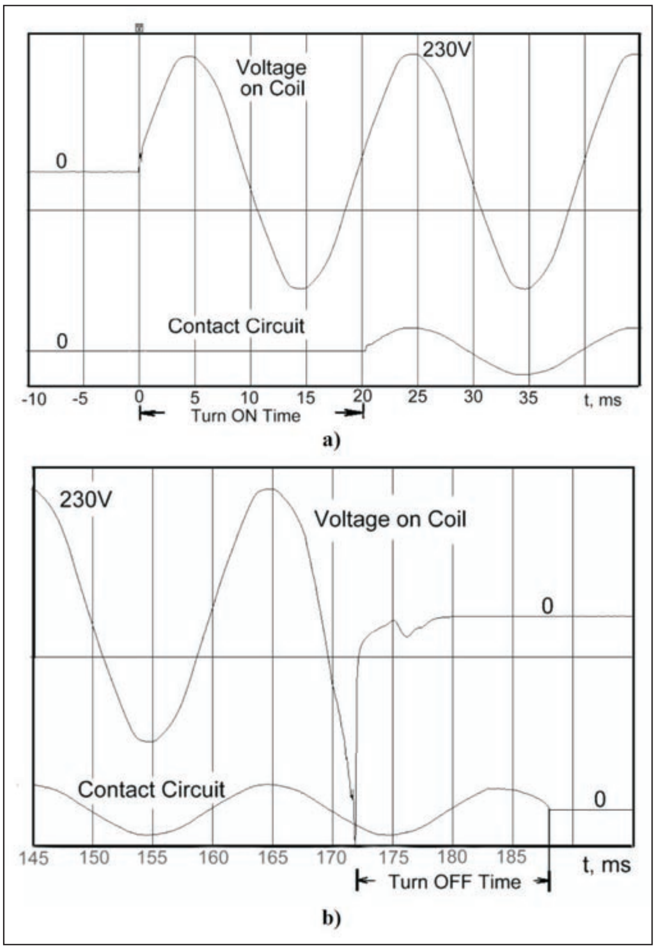

Fig. 6: Oscillograms of contactor type 3TF54, switching-on and switching-off.

to 150 – 135 V causes vibration of the contactor magnetic system of a magnitude that is sufficient to close and open its main contacts. The same phenomenon arises when the AC voltage across the coil increases from 0 up to 160 – 185 V. A contactor working in such conditions, even at a single voltage sag (to level 135 – 150 V during 100 – 200 ms), can cause multiple interruptions of the main voltage in the auxiliary AC network. The same result appears when connecting the contactor's coil to a power supply with a voltage of 150 – 170 V.

Offered solution for the problem

In view of character of the loads fed from the auxiliary AC network in substations, the technical solution offered for contactors intended for use in manufacturing plants, is not the correct technical solution for a 400 V substation network, because, through closed contactor's contacts, the short sags will affect sensitive equipment.

In our opinion the problem must be solved not by means of retention of the contactor in the closed position at voltage sags, but by means of the rapid (during 10 – 12 ms) disconnection of the contactor's coil at voltage levels dropping below 160 V and returning it to initial condition at voltage level restoration up to 185 V with time delay 5 – 10 s. A single interruption of 5 – 10 s duration in the auxiliary 400 VAC substation power network does not cause serious disturbances in the substation equipment due to a power battery feeding most of the important substation consumers.

For fast contactor disconnection at voltage network drops most electronic relays available in the market are not suitable because their minimal reaction time is of the order of 100 ms. During a time interval of this duration, the contactor will make several disconnections and connections of the main power.

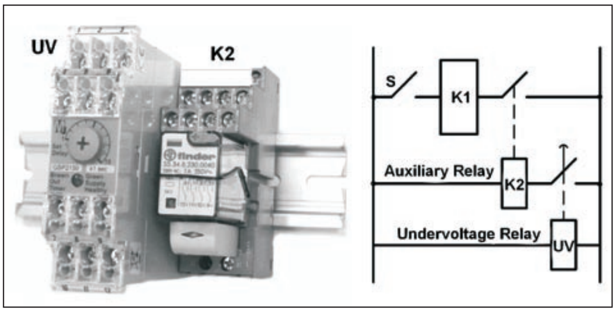

Fig. 7: Device for fast forceful disconnection of the main contactor at voltage sag.

As a result of our research only a few types of the devices suitable for contactor's control were found, Fig.7. One of them is an under-voltage relay combined with timer: Brown-out timer type GBP2150. The reaction time of this device for voltage drops of 30% is only 5 ms. The release time after voltage restoration up to 80% can be adjusted to intervals of 1 to 10 s. Another good example is the under voltage relay type PKH-1-3-15. Such devices are ideal solutions for our purposes. For decreasing loads on the output contacts in these devices an additional auxiliary fast electromagnetic relay, type 58.32.8.230, with heavy output contacts and a release time 3 ms is employed.

Conclusion

For manufacturing plants with electrical motors as dominant consumers and for power substations with power electronic equipment as dominant consumers in 400 V AC networks different methods must be used in contending with voltage sags. In the first case devices with capacitor or compact switching power supply for retention of the main contactor in closed position during short voltage sags, as described above, can be used. In the second case it is recommended using a simple device for fast forceful disconnection of the main contactor at voltage sags below 25 - 30%.

References

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