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Distributed Automatic Transfer Bus and Restoration Using IEC61850

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ABSTRACT

The proliferation of technology has made global conduction of business increasingly dependent upon the availability of reliable power. As a result, alternate power systems are being installed and expanded to protect the broadening scope of critical electrical loads. Bus transfer restores designated critical loads to an alternate source when utility derived service becomes inadequate or goes out of service due to any contingency. This paper describes the practices, requirements and implementation of bus transfer of motor loads to an alternate source of power. A new high-speed automatic bus transfer scheme using IEC 61850 communication protocol instead of hardwiring is proposed which includes the restoration functionality and the realization of the scheme by using modern protection devices and intra-substation communication facilities.

Bus transfer is the practice of transferring a load bus, which comprises mostly of induction motors to an alternate power source in any power plant or industrial plant when the normal power source fails or needs to be tripped to ensure continuity of plant operation. Any improper and insecure bus transfer can cause serious damage to the motors, their connected loads and for the process continuity. The bus transfer has to happen at a very high speed in a secure way so as not to have any adverse economic impact on the plant operation. Bus transfer requirements vary with different plants according to their connected loads and plant operating practices. In this paper, the typical bus transfer schemes adopted by industries analyzed. A modern automatic high-speed bus transfer method is presented in this paper and the automatic bus transfer scheme realization using modern IEDs and intra-substation communications based on peer-peer communications with IEC 61850 protocol. Different Schemes with 3, 4 and 5 breakers involving the interaction with an emergency Generator or line are analyzed, including the automatic restoration

1 INTRODUCTION

Bus transfer is the practice of transferring a load bus, which comprises mostly of induction motors to an alternate power source in any power plant or industrial plant when the normal power source fails or needs to be tripped to ensure continuity of plant operation. Any improper and insecure bus transfer can cause serious damage to the motors, their connected loads and for the process continuity. The bus transfer has to happen at a very high speed in a secure way so as not to have any adverse economic impact on the plant operation. Bus transfer requirements vary with different plants according to their connected loads and plant operating practices [1].

2 TYPES OF AUTOMATIC BUS TRANSFER

Bus transfer may be categorized in three general types:

- Parallel (hot) Transfer
- Fast Transfer
- Delayed Transfer

2.1 Parallel Transfer

This is the method of transferring for unit start-up and planned shut-downs. In this method, the start-up source (SST) breaker is closed before the Unit Auxiliary Transformer (UAT) source breaker is opened. In this method there is no transient on the motor bus because all the time the different components of the system are synchronized. This method requires, at a minimum, a sync-check relay to assure that the phase difference across the breaker being to be closed, is within the acceptable limits.

2.2 Fast Transfer

In this type, UAT source breaker is opened prior to SST breaker closing. The bus must always be completely disconnected from both sources for a short period of time. The only supervision is done through a fast sync-check relay. Extensive analysis of the load is needed before to apply this method in order to determine the exact characteristic of voltage and phase angle of the motor bus and so to determine the exact moment when the order to close the SST breaker must be done, in order to minimize the transient torque in the motors.

2.3 Delayed Transfer

There are two types of delayed transfer:

- a) In phase. It is essentially a high speed automatic synchronization between the motor bus and the start-up source. The start-up source must be closed so the breaker contacts make at the time of zero phase coincidence.
- b) Residual voltage. Involves waiting until the bus voltage drops below a predetermined point before closing the start-up source breaker: typically 25% of the nominal.

3 BUS VOLTAGE AND PHASE DURING TRANSFER

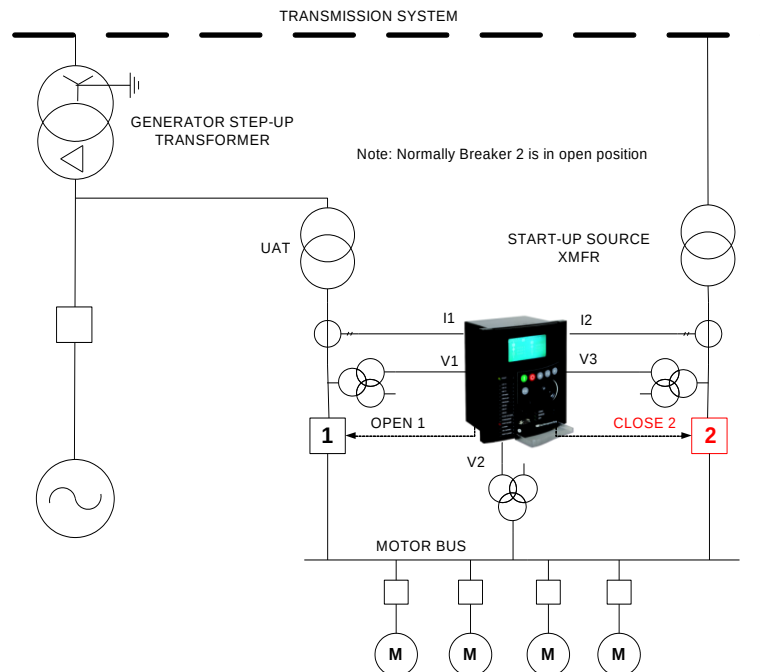


Fig. 1: Bus configuration used in thermal plants

In this configuration one or two units wired can be used and breaker 1 is normally closed and breaker 2 normally open, when UAT is disconnected, automatically breaker 2 is closed to maintain the service to the motors of the plant. Usually the a fast transfer scheme is applied.

In general, the voltage characteristics of a motor bus during transfer is governed by the motor loads operating at the time of the transfer. When a bus is disconnected from the UAT, the motors will generate a voltage due the energy stored in the motor fields. The initial value of the voltage depends on the integrity of the Power Source prior to disconnection. A three-phase fault in the UAT generator step-up transformer or on the high voltage bus near the plant may completely de-energize the motor fields and the resultant voltage will be minimal. However for all other cases a significant voltage will be induced on the motor bus. The induced voltage will have a dynamic amplitude and phase characteristic that will depend on the inertia of the motors loads and the field energy stored in the motors.

When the bus is disconnected, the large motors with high inertial loads will act as induction generators supplying power to the smaller motors. The total bus voltage will have a complex average response such that the voltage will decay faster than the voltage for the largest individual motors and slower than for a single small motor.

The open circuit voltage per hertz V_{oc} can be calculated as using the law of cosines. Assuming the reserve source is operating at 60 Hz prior to transfer:

$$V_{oc} = \sqrt{V_R^2 + \left(\frac{V_B}{f}\right)^2 - 2 \frac{V_B}{f} * V_R \cos \theta}$$

f = bus frequency in per unit at 60 Hz.

$V_R = 1$ p.u. at 60 Hz.

This voltage should be limited to a value of 1.33 per unit volt/hertz as established by ANSI/IEEE standard C50.41-77: Polyphase Induction Motors for Power Generating Stations.

Using the configuration from Fig 1, some calculations were made to determine the critical parameters needed to evaluate in order to identify the possibilities of a Fast Transfer Scheme.

The Motor model, parameters and operating conditions are only referential and the only purpose is to shown the phenomenon. A similar approach must be done for each particular case before to decide the type of transfer scheme to use.

When the bus motor is disconnected, frequency and voltage drop with a variable speed that depends on the motors inertia, load and operating conditions. The figure in red color shows the motor bus voltage and the blue the Start-up bus voltage that for this particular example initially has the same angle as the UAT bus.

If we see how the two voltages components (Start-up bus used as reference and Motor bus) Evolves we can see the Fig. 2.

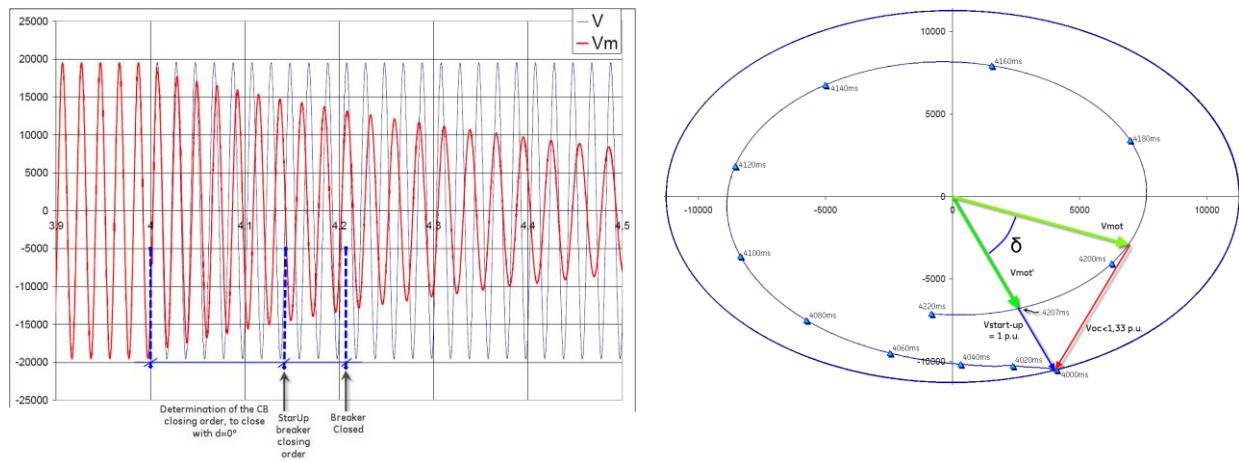


Fig. 2

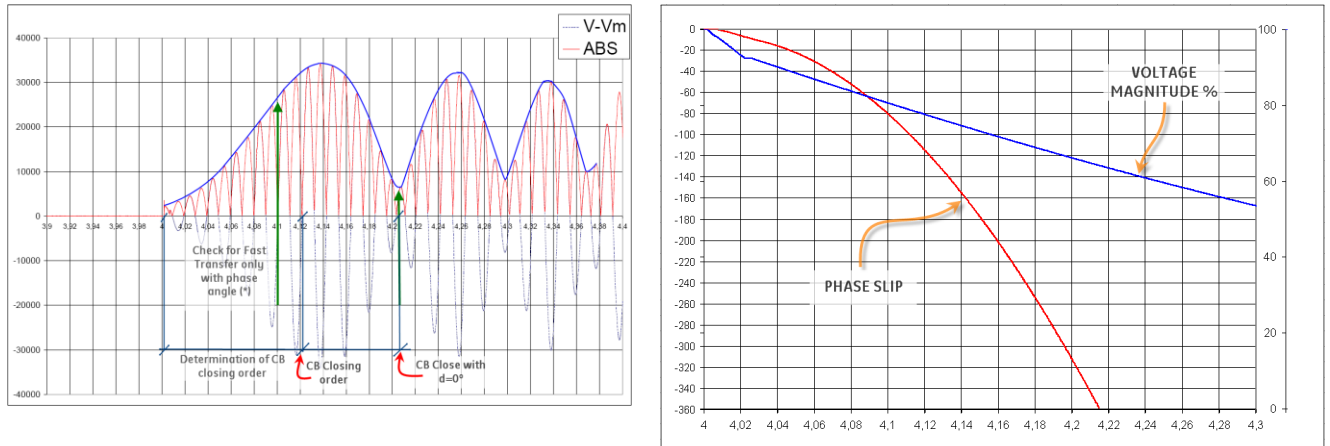


Fig. 3: Evolution of the Voc voltage in the time (left) and Motor Bus voltage and angle (right)

In the Fig. 3 we can see the Motor Bus voltage magnitude and angle during the time after the UAT disconnection.

4 FUNCTIONS REQUIRED TO SUPERVISE TRANSFER

4.3 Fast Transfer

Fast transfer requires that the start-up source breaker be closed before the phase angle moves not higher than 30 to 45° and voltage drops less than 20% from the nominal approximately (residual voltage higher than 80% of the nominal value). Fast transfer requires a high speed sync-check function that can drop out fast enough to prevent the start-up source breaker from closing on a large or rapidly moving phase angle.

Apart from the angle condition, the relay must consider that the maximum difference voltage as well as the maximum frequency difference is not reached at any time to fulfill with the requirements of the ANSI/IEEE standard C50.41-77.

4.2 In Phase Transfer

In Phase Transfer is defined as closing the Start-up source breaker when the bus voltage is in phase with the start-up source voltage. Basically the criteria is to allow the closing in a voltage range of 33% to 80% of the nominal voltage using an algorithm to predict in advance when the phase condition will occur and initiate closing the start-up source breaker ahead of zero phase by the breaker closing time.

4.3 Residual Voltage

The residual voltage function is used to detect when the bus voltage drops below a predetermined level and then to initiate closing the start-up breaker w/o any additional supervision. Normally this function is only allowed if the voltage drops under 25% of the nominal value. A feature that may be required is a load shedding output which can be used to strip loads from the bus prior to closing the start-up breaker. This only applies to motors connected through CB, because motors connected through Contactors have a natural load shedding based on voltage magnitude.

5 APPLICATION CONSIDERATIONS

Before to evaluate the suitability of the Fast transfer scheme it is needed to evaluate the following parameters:

- 1) To determine the characteristics of the bus residual voltage either analytically or experimentally.
- 2) Closing time of the CB which will restore power to the motor bus.
- 3) Initial Slip Frequency of the Motor Bus Residual Voltage.

- 4) The time required for the Motor Bus residual voltage phase angle, relative to the new power source, to rotate (slip) through a complete 360° angular rotation. This will be the Transfer Time.

6 TRANSFER BUS IMPLEMENTATIONS

Transfer Bus has different levels of sophistication that corresponds with the specific Bus configuration.

The most typical Bus configuration used in Industrial Installations is the one shown in the Figure 4

Incomer A and Incomer B each feeding to their respective motor loads. The two sources are tied by means of a tie breaker (3). Incomer A is connected to its motor load through a station transformer and station breaker (1) and similarly Incomer B is connected to its motor load through a station transformer and station breaker (2).

The Automatic Transfer scheme is intended for application to a set of three circuit breakers on a Main-Tie-Main arrangement, two of which (Incomers A and B) connect sources of electrical energy to two busses which could be paralleled through the Bus Tie breaker. The normal system configuration is with both incoming breakers closed and the bus tie breaker open. The transfer scheme implemented is known as Open Transfer, with an “Open before Close” operation sequence in a “Fast Transfer Scheme” (according to ANSI C50.41 2000 standard means a Transfer in less than 10 cycles); this means that the faulty incomer is removed from service before the tie breaker is closed (sync check permission will supervise the breaker closing).

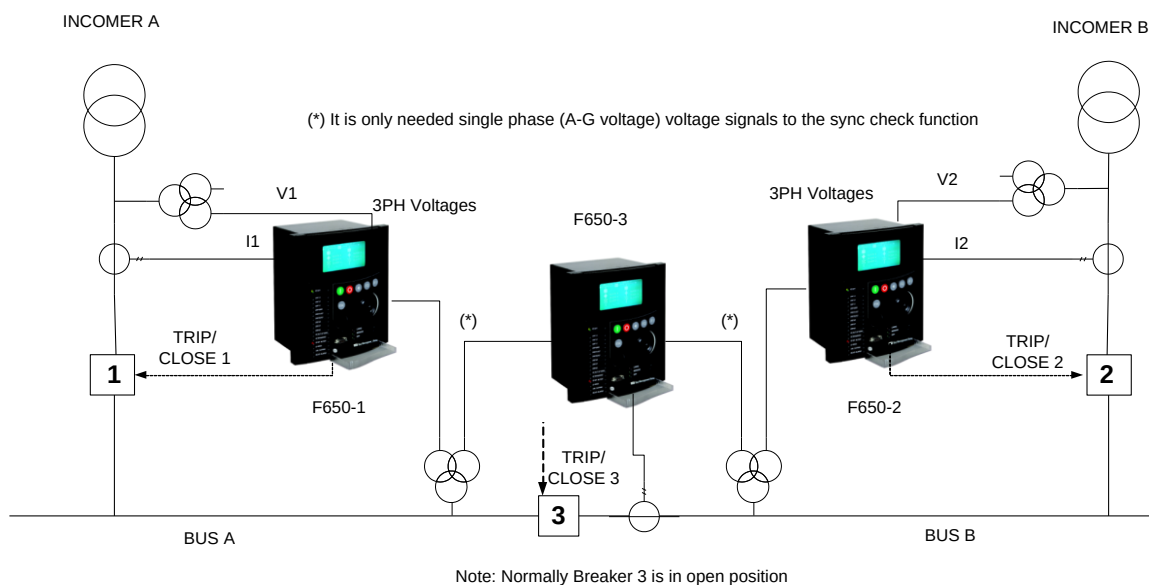


Fig. 4: Typical Bus Configuration used in Industries

An automatic bus transfer scheme requires a lot of logical inter connections and electrical interlocks between various relays, CBs, isolators, fuses etc. The bus transfer scheme has to determine the type of bus transfer method on these logical and electrical interconnections. The bus transfer relay has to continuously monitor certain key system elements to determine the safe and secure way to conduct a bus transfer.

With conventional relaying technology it means a lot of hardwiring between relays resulting in two to three panels to have a bus transfer scheme with all controls. With the development of modern IEDs, which can communicate with other IEDs through peer-peer communication using the communication protocol IEC61850, the realization has been reduced to less wiring, component cost reduction, increased reliability and the event and oscillographic recording facility for transfer analysis. Modern IEDs offer a wide variety of facilities not present with conventional technology which include built in programmable logic controller, timers, multiple digital inputs and outputs, analog output

facilities etc, which can help significantly in realizing an automatic bus transfer scheme. We can see in Figures 5 and 6 a pair of examples.

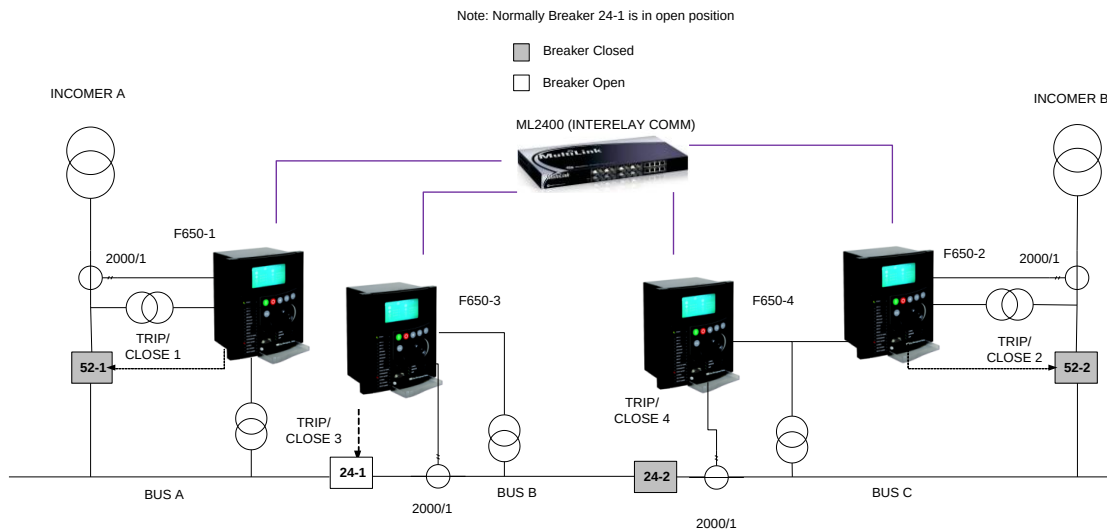


Fig. 5: A variant of the Bus Configuration with 4 breakers (Breaker 24-1 operates normally open)

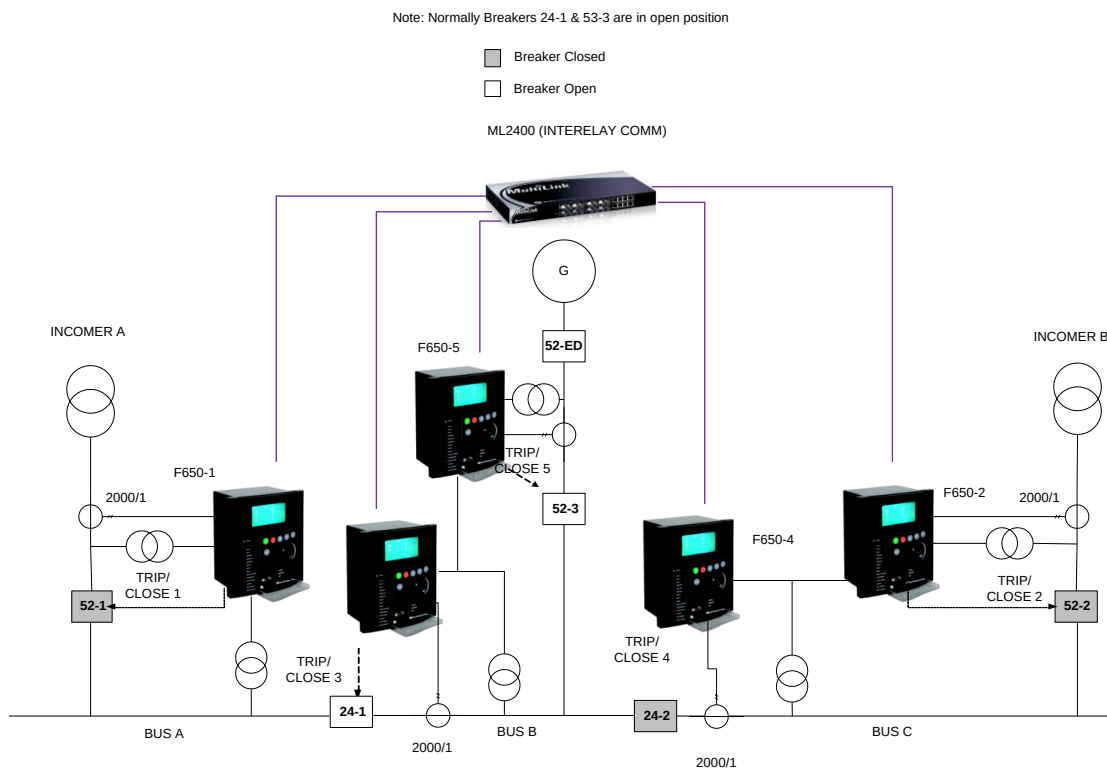


Fig. 6: A bus configuration used in thermal plants with 5 breaker and an emergency diesel feeder

In relation with Figure 6, in normal operating condition, 52-1, 52-2 & 24-2 are in closed position, 24-1 is in open position. 52-3 and 52-ED connected to the Diesel Generator are open also.

In case of loss of voltage on 52-1 or 52-2, but not in both, the auto-changeover system will open the relevant line and will close the bus-tie (24-1) in order to feed the bars A+B+C with the same incoming line.

When the failed line is restored, the respective line breaker will be closed (Each incoming line breaker is equipped with a dedicated time delay relay to have a time delay on breaker reclosure, in order to set the closing time after voltage restore), then 24-1 will open after a short parallel condition

between line 1 and line 2. In case of loss of voltage on both 52-1 and 52-2 there is a sequence to prepare the closing of the Diesel generator and to produce an automatic closing of the CB 52-3 when the “SYNC” conditions are fulfilled. In this condition when the failed lines (52-1, 52-2) are restored, the respective breakers are closed in an automatic sequence:

- If the Voltage is recovered in only one breaker (52-1 or 52-2), it will be proceed to close the respective breaker doing a short parallel with the Diesel Generator, after that, automatically 52-3 is opened after receive the opening confirmation from the breaker 52-ED (Generator Breaker).
- If the voltage is recovered in both breakers (52-1 and 52-2), there is an external interlock scheme that enable the recover in the first line available (breaker 52-1 or 52-2) doing a short parallel with the Diesel Generator, after that, automatically 52-3 will be opened after receive the opening confirmation from the CB 52-ED. After this operation, 24-1 will be automatically opened.

As we can see, because the level of sophistication of the transfer and recovery schemes, a harwired solution, particurarly when the CB's are not in the same location, is not viable. The solution using a distributed scheme with peer-to-peer communication using the communication protocol IEC61850, brings operating times similar to the ones obtained with a hardwired solutions.

7 CONCLUSIONS

The application of a Fast transfer and in phase transfer schemes using appropriate algorithms (particularly the sync-check algorithm), presents interesting possibilities, but subject to the following limitations:

1. Immediate Fast transfer (in less than 30 ms as decision time) only is possible for motor loads with sufficient inertia to assure a closing angle (30° maximum) in a time not higher than 100 ms. after the opening of the UAT or Incomer CB. 100 ms represents the sync-check phase angle verification time plus the CB closing time. Intensive studies and a good knowledge of the loads are needed before to apply this method. This is the method with the highest risk in the application. The advantage is the speed, but as in any other applications, higher speed means less reliability.
2. Delayed in phase transfer scheme (this is other type of fast transfer scheme) it is also limited to motor loads with sufficient inertia to assure a correct calculation of the time when $\delta=0^\circ$. Having in count that the predictive algorithm needs a minimum time of 100 ms of data for a correct angle calculation, a complete phase shift of 360° must be in less than 180 ms. (we assume 80 ms as breaker closing time). In this case it is also important a good knowledge of the loads and a complete calculation of the performance in order to verify if this method can be applied w/o any risk. Another possible method is to collect data from field test, as the Motor Bus voltage (magnitude and angle) after being disconnected from the UAT or from the respective Incomer.
3. Residual voltage function can be applied practically w/o time limitation. In this case it is important to incorporate a load shedding scheme, particularly if the Start-up source has not enough power for the simultaneous motor starting of the motors already connected to the Motor Bus after the voltage collapsed. This can be critical if the Start-up source consist of only a Diesel Emergency generator. In this particular case, probably a transfer scheme will be not possible to apply.
4. The use of the IEC61850 communication protocol has facilitate the implementation of the transfer bus schemes in more complex arrangements and with more functionality added, as Automatic Incomer Restoration

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