Dynamic Modeling of an Improved In-Phase Motor Bus Transfer Scheme

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***Abstract*-- This paper discusses currently used motor bus transfer methods, and presents a new method to successfully perform an in-phase motor bus transfer to connect a motor bus to an alternative power source in the event of a supply disruption. Industrial facilities with large motor loads typically have two independent power supplies to increase the robustness of the electrical power supply. If one of the two power supplies becomes unavailable due to a fault on the power line, the two buses are paralleled to keep the facility fully operational. Induction motors comprise the bulk of the load on the buses in question, requiring that the voltages of the buses must be in synchronism before the two buses are connected. The machines supplied by the source that experiences the failure start to slow down when the voltage sags then is interrupted. The potential for severe transient torques on the motor shafts upon resynchronization complicates the transfer process and the transfer scheme must keep the torques to safe levels. This paper presents an analysis of a new in-phase bus transfer scheme that does not require extensive studies prior to commissioning and demonstrates performance through transient simulations.**

***Keywords*: Motor Bus Transfer, Induction Machine, Modeling.**

I. INTRODUCTION

Fast motor bus transfer schemes were first envisioned in power generating plants in order to keep boiler feeds pumping and running during emergency conditions. The first bus transfers were initiated once residual voltage of the motors had dropped below 25% of the nominal voltage to limit the adverse effects on the motor and their connected rotating loads. However, the closing time of the available circuit breakers were tens of cycles; consequently, reliable fast or in phase motor bus transfer schemes could not be realized using these breakers. Therefore, at the same time as the interest in fast motor bus transfer schemes were being explored, onboard energy storage circuit breakers were being developed. These circuit breakers stored the opening and closing energy in springs and offered consistent closing times of a few cycles.

In the early 1980s engineers proved that there is a torsional interaction between the electrical and mechanical systems of a motor and its driven load. If the electromagnetic air gap torque contains a frequency near or at the torsional resonance frequency of the power system; large transient torques can be generated during a fast or in-phase transfer.

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This paper proposes an analytical technique for designing improved in-phase bus transfer scheme in the event of loss of power to the facility. This paper highlights a framework based on steady-state eigenvalues and transient coefficients and the need for a detailed transient model of three phase induction machines. Based on this approach this paper proposes a new method for in-phase motor bus transfer that ensures safe and robust transfer. With the models completed, the dynamic response of the three-phase induction machines will be analyzed and recorded through transient simulations.

II. MOTOR BUS TRANSFER

This paper will exclusively concentrate on the Open Transition Transfer type of transfer, since this is the method that is most commonly used in industry today. The open transition transfer is classified into three basic methods:

- The fast transfer;
- The in-phase transfer;
- The residual voltage transfer.

A way to illustrate the three transfer methods is by using a graphical illustration in Fig. 1 which depicts the decay in both the voltage magnitude and phase angle after the motor bus has been disconnected from its primary power source. The three zones that correspond to the three open transition transfer methods found in typical literature [1] are indicated in Fig.1. As seen below, the red line is the phase angle of the motor bus relative to the new bus. The blue line is the motor bus voltage magnitude. The in-phase transfer uses the phase angle difference, and the residual voltage transfer uses the voltage.

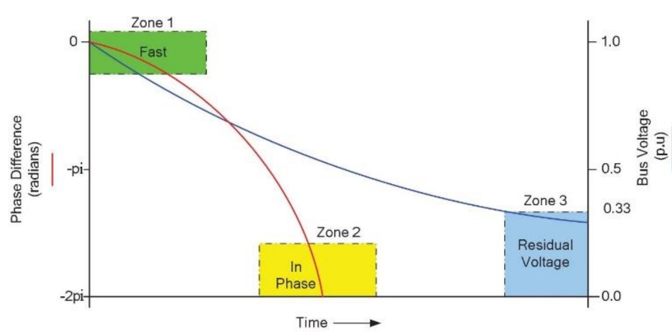

Figure 1: Sketch showing the three zones during which a motor bus transfer can occur, namely the fast transfer, the in-zone transfer and the residual voltage transfer.

A. Fast Transfer

To implement the fast transfer method, facilities use high speed circuit breakers with a closing time of 1 cycle (16.67 ms) or less. In this mode, the isolated bus is connected to the alternate (auxiliary) supply if the voltage magnitude and phase angle difference is within zone 1 specified in Fig. 1. Typical industrial circuit breakers are too slow with a closing time of approximately 3 – 4 cycles (50 – 66 milliseconds) [2].

B. The In-Phase Transfer

For an in-phase transfer the voltage magnitude on the motor bus must be greater than 0.33 of the rated voltage. Secondly, the voltage angle difference and the rate of change of voltage between the motor bus and the alternate source must result in a volts-per-hertz difference of less than 1.33 V/Hz between the bus and the alternative source [1]. Zone 2 in Fig. 1 shows when the angle range difference range where the volts-per-hertz difference between the alternative source can be calculated. In practice this calculation is no simple task when the frequency of the voltage is changing. Extensive simulation studies are required prior to commissioning to ensure that no possible condition will lead to excessive torques during the fault or motor transfer. It is not possible to cover all possible conditions in most cases.

C. The Residual Voltage Transfer

For a residual transfer to occur the voltage of the motor bus must be below the residual voltage limit (typically 0.25 p.u.). A residual transfer is unsupervised by the phase angle or slip frequency as it is not possible to exceed the 1.33 V/Hz limit set by the in phase transfer due to the voltage decay. Two factors have to be taken into account for a residual voltage transfer to be successful: 1.) the under voltage protection time out trip of the motor and 2.) the stall point of the motors when the frequency is too low. Therefore, the residual transfer has to be coordinated with the under voltage trip time of the motor contactors on the bus and the inertia of the motors and the load on the bus during the time that the motor bus is isolated from all power sources in order to be able to act before the motors trip or stall.

III. Induction Machine Modeling To Develop Transfer Method

Since this paper discusses the motor during a transient period, the behavior of the motor will be analyzed using the “dq0” reference frame. In the “dq0” reference frame a three phase induction motor can be fully described using equations (1)-(6). Where v_d is the direct axis voltage, v_q is the quadrature axis voltage, i_d is the direct axis current and i_q is the quadrature axis current. Additionally, subscript “s” signifies stator quantities, and subscript “r’ refers to the rotor referred quantities. And r_s and r_r are the stator and rotor resistances respectively. And where L_m, L_s and L_r are the magnetizing, stator, and rotor inductances respectively. Lastly, where p is the derivative operator.

$$v_{ds} = (r_s + pL_s) \cdot i_{ds} - \omega L_s \cdot i_{qs} + pL_m \cdot i_{dr} - \omega L_m \cdot i_{qr} \quad (1)$$

$$v_{qs} = \omega L_s \cdot i_{ds} + (r_s + pL_s) \cdot i_{qs} + \omega L_m \cdot i_{dr} + pL_m \cdot i_{qr} \quad (2)$$

$$v_{0s} = (r_s + pL_{ls}) \cdot i_{0s} \quad (3)$$

$$v_{dr} = pL_m \cdot i_{ds} - (\omega - \omega_r)L_m \cdot i_{qs} + (r_r + pL_r) \cdot i_{dr} - (\omega - \omega_r)L_r \cdot i_{qr} \quad (4)$$

$$v_{qr} = (\omega - \omega_r)L_m \cdot i_{ds} - pL_m \cdot i_{qs} + (\omega - \omega_r)L \cdot i_{dr} - (\omega - \omega_r)L_r \cdot i_{qr} \quad (5)$$

$$v_{0r} = (r_r + pL_{lr}) \cdot i_{0r} \quad (6)$$

In most cases the motor windings are connected in delta or ungrounded wye so that no neutral (ground) current can flow. Therefore, in both instances, assuming no external v_0, the neutral axis voltages v_{0s} and v_{0r} are zero, the induction motor is now fully described by (1), (2), (4), and (5), which can be simplified to:

$$v_{qds} = v_{qs} - j \cdot v_{ds} \quad (7)$$

$$v_{qdr} = v_{qr} - j \cdot v_{dr} \quad (8)$$

Applying (8) to (4) and (5) and using the arbitrary rotating reference frame where $\omega = \omega - \omega_r$, the complex vector equations for a squirrel cage induction motor, where the applied rotor voltage vqdr = 0, are shown in (9) and (10).

$$v_{qds} = \{r_s + L_s(p + j\omega)\} \cdot i_{qds} + L_m(p + j\omega) \cdot i_{qdr} \quad (9)$$

$$0 = \{L_m\big(p + j(\omega - \omega_r)\big)\} \cdot i_{qds} + \{r_r + L_r\big(p + j(\omega - \omega_r)\big)\} \cdot i_{qdr} \quad (10)$$

During the open interval period the stator current is zero and therefore (10) reduces to (11).

$$v_{qds} = L_m(p + j\omega) \cdot i_{qdr} \quad (11)$$

Equation (13) is obtained by substituting i_{qdr} into (11) and differentiating with the assumption that deceleration can be assumed to be constant and the stator voltage can be computed. The deceleration of the rotor and the connected load is determined as follows [3], [4].

$$\alpha = \frac{-T_{load}}{J_{motor} + J_{load}} \quad (12)$$

$$v_{qds\_tl}(t) = L_m\left(j\omega - \frac{1}{\omega_e \cdot \tau_r}\right) \cdot i_{qdr}(t_0^+) \cdot e^{\left(\frac{1}{\tau_r} + \alpha\right)t} \quad (13)$$

$$i_{qds}(t) = C_1 e^{\lambda_1 t} + C_2 e^{\lambda_2 t} + I_{ss} e^{j\omega t} \quad (14)$$

$$i_{qdr}(t) = C_3 e^{\lambda_1 t} + C_4 e^{\lambda_2 t} + I_{sr} e^{j\omega t} \quad (15)$$

$$T_{em} = L_m Im\left(i_{qds} \cdot i_{qdr}^*\right) \quad (16)$$

The eigenvalues of the motor must be found to calculate the motor currents and subsequent torque developed by the motor at the instant the motor is reconnected to the alternative power source. Therefore, a highly detailed transient model of an induction machine must be used to calculate the torques produced during the transient period. These equations can be used to analytically develop and test a transfer scheme, in this case to ensure torque levels stay within limits. The full derivation analysis is in [5]. Simulation models will also need a suitable motor model.

IV. Proposed Method

The proposed method performs an in-phase transfer by calculating the slip angle between the motor bus and the alternative source. As noted in Section II this is complicated because the frequency of motor voltage is changing. This is achieved by calculating the magnitude and angle of both the voltage on the motor bus and the alternative power source. The relative slip (phase difference) between the two voltages is calculated from the voltage angle. If the breaker closing time and the slip frequency between the two voltages are known, the exact angle (moment in time) is calculated to send the close signal to the circuit breaker to initiate closing. Issuing the breaker closing signal before the two voltages are in perfect synchronism allows the two voltages to be in near synchronism when the contacts close.

Once the input signals have been conditioned and digitized, the alpha and beta quantities for the voltage are calculated using (17) and (18).

$$V_d^0 = V_\alpha = \frac{2}{3}\left(V_a - \frac{V_b}{2} - \frac{V_c}{2}\right) \quad (17)$$

$$V_q^0 = V_\beta = \frac{1}{\sqrt{3}}(V_b - V_c) \quad (18)$$

From the alpha and beta quantities, a vector is formed using (19) where the magnitude and angle of the respective signals are calculated using (20 and 21). Equations (17)-(22) are repeated for currents as well.

$$V_{\alpha\beta} = V_\alpha + jV_\beta \quad (19)$$

$$V_{\alpha\beta\_MAG} = \sqrt{{V_\alpha}^2 + {V_\beta}^2} \quad (20)$$

$$V_{\alpha\beta\_ANG} = \text{atan}\left(\frac{V_\beta}{V_\alpha}\right) \quad (21)$$

In this way, a single signal is obtained that represents the three phase voltages on the motor bus and the alternative power source. Similarly, a single current represents the current being generated or consumed by a motor on the motor bus.

Since the voltage that is measured at the motor bus is the voltage at the terminal of the motor(s) and not the voltage behind the transient reactance of the motor, the voltage behind the transient reactance of the motor still needs to be calculated. The voltage behind the transient reactance is calculated from (22) by using the voltage at the motor bus, the current of the motor and the motor parameters. Where: $V_{\alpha\beta\_bus}$ is derived using (17)-(19) from the measured bus voltage; $I_{\alpha\beta\_mot}$ is derived using (17)-(19) from measured motor current; R_S is the stator resistance in per unit. $L_{S'}$ is the stator transient inductance in per unit.

$$E_{\alpha\beta\_mot} = V_{\alpha\beta\_bus} + R_S I_{\alpha\beta\_mot} + L_S{}' \frac{dI_{\alpha\beta\_mot}}{dt} \quad (22)$$

To perform the in-phase transfer the close signal must be sent to the circuit breaker before the two systems come into synchronism. This way when the circuit breaker contacts do close the two system will be in perfect synchronism. Typically, a circuit breaker has a minimum and a maximum closing time. The maximum closing time has been used for this case. Krause et al. [6] indicate that closing the circuit breaker such that the motor voltage lags the voltage of the alternative source results in a lower transient airgap torque in the motor than if the motor voltage were to lead the voltage of the alternative power source.

Therefore, this method is designed to close the circuit breaker when the motor bus voltage lags the alternative source voltage, resulting in a lower transient airgap torque, as recommended in [6].

This method offers the following benefits:

- It is immune to frequency changes on the motor bus and alternative voltage source;
- It does not require any system studies;
- It requires minimal settings (the breaker closing time and the parameters of the motor with the highest inertia).
- It works on buses with multiple motors with differing inertias and loads

The drawbacks of this method are as follows:

- It requires the user to enter in the closing time of the transfer breaker;
- It requires one set of current inputs (if you want to sync the alternative source with the voltage behind the transient reactance of the motor),
- It requires the user to enter in the motor parameters for the motor with highest inertia. However, the method will work adequately even if no motor data or current information is available from the motor

Fig. 2 shows a flow chart that can be used to determine whether a specific industrial load such as an industrial facility or mine will experience a successful in-phase motor bus transfer.

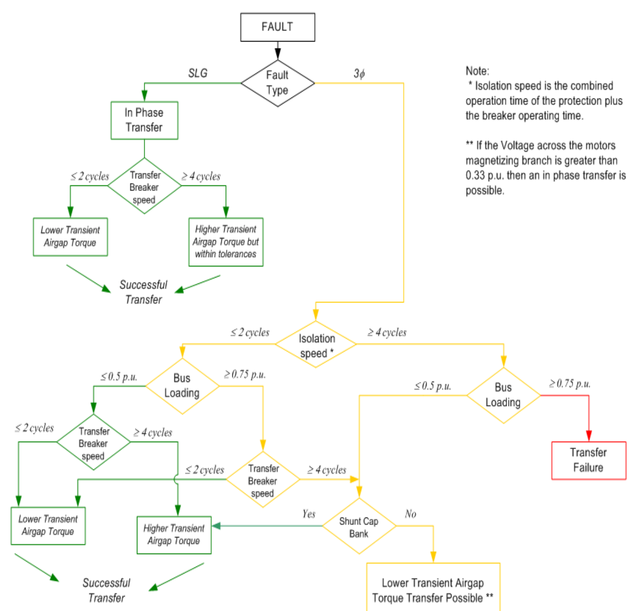

Figure 2: Flow diagram that can be used beforehand to determine whether a specific industrial installation will be suitable for an in-phase motor bus transfer scheme.

V. Model Description

To verify the performance of the proposed method, a model of a simple industrial substation consisting of two independent motor buses as shown in Fig. 3 was modeled in the Real Time Digital Simulator (RTDS). The RTDS was chosen for this method to simulate the breaker reclosing time, and machine analysis for real time operations. Two motor buses are fed from two independent sources S1 and S2. If one source is out of service, the two buses can be powered by the other independent source by connecting the two buses together via the bus coupler (BC).

The model will consist of two independent motor buses (Bus 1 and Bus 2) being fed by two independent 34.5 kV sources via two transmission lines. The transmission lines terminate at a 20MVA 34.5/2.3 kV transformer. The transformers have an impedance of 10%.

Each motor bus is connected to three induction motors, which are a mix of 500 Hp and 1000 Hp induction motors. These motor are modeled using the built-in dynamic motor models. The motors will drive loads with inertia constants (H) ranging between 0.527 – 1.15 seconds.

The dynamic loads are configured such that they behave as constant loads i.e., they consume a constant 0.1 to 5.0 MW's and a constant 0.1 to 5.0 MVAR's if the voltage is above 70% of the rated bus voltage. If the voltage drops below the 70% of the nominal bus voltage these loads become constant impedance loads. The three stage shunt capacitor bank can provide 40, 80, or 120kVAR to each bus. These conditions are varied over the set of simulations to verify successful transfer.

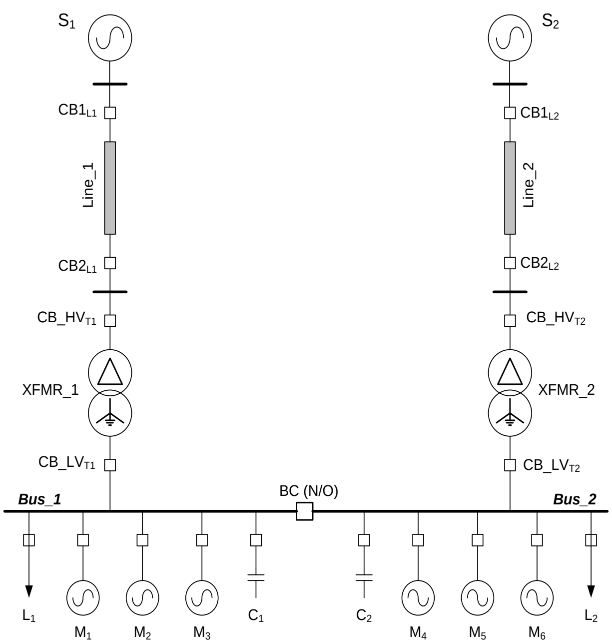

Figure 3: Model power system configuration

Table 1: Motor Terms Definition

f_{nom}	Nominal system frequency
I_{rated}	Rated current
R_S (R_a)	stator resistance
X_{LS} (X_a)	stator leakage impedance
X_{MD0}	unsaturated magnetizing impedance
Number of rotor cages	single bar rotor machine
R_R	rotor resistance
X_{LR}	rotor leakage impedance
σ	coupling coefficient
$L_{S'}$	transient reactance
Z_{BASE}	base impedance ohms

Table 2: Motor Data

Parameter	1000 HP Motor	500 HP Motor
f_{nom}	60 Hz	60 Hz
I_{rated}	188 A	94 A
R_S (R_a)	0.003 p.u	0.018 p.u
X_{LS} (X_a)	0.07 p.u	0.085 p.u
X_{MD0}	2.00 p.u.	3.807 p.u.
Number of rotor cages	1	1
R_R	0.003 p.u	0.0035 p.u
X_{LR}	0.07 p.u.	0.085 p.u.
σ	0.066 p.u	0.043 p.u
$L_{S'}$	0.138 p.u	0.168 p.u
Z_{BASE}	7.064 ohm	7.064 ohm

VI. Simulation Cases

A fault will be applied to line 2, in order to clear the fault, the two terminals of line 2 will be disconnected namely source 2 (S2) and motor bus 2 (Bus 2). Once Bus 2 is isolated from the line, the in-phase motor bus transfer algorithm is enabled and transfers Bus 2 to the alternative power supply, namely Bus 1. This is achieved by using the primary plant model and the in-phase motor bus transfer logic implemented in the simulation model with a detailed emulation of relay.

A transfer is considered successful if the following criteria are met: 1.) The motor bus is connected to the alternative power source when the two voltages are in synchronism. The angular difference should not be more than 30 degrees, 2.) No voltage collapse after the motor bus transfer occurs, 3.) No overload of the alternative power source under steady state operating conditions, 4.) The airgap instantaneous torque must not exceed 6 p.u. The success of a motor bus transfer after a fault condition on the power system depends on many different factors. This paper will concentrate on the following operating conditions:

1. Fault type

SLG faults are the most common types faults on the power system. They constitute approximately 80% of all faults on the power system with overhead lines. SLG faults may also produce the highest phase fault current and the largest single phase voltage depression.

2. Fault duration

The longer the duration of a fault on a power system the more severe the consequence are due to the fault. Typical medium voltage circuit breakers have an opening time between 2 – 4 cycles. Should a fault last longer than approximately 6 cycles on a power system, a breaker failure condition will be declared. Fault durations will be varied between 33ms to 67ms for the simulations.

3. Source strength

The stronger the source, the greater the contribution of fault current from the source to the fault and less of the fault current comes from the motor bus. In addition, the stronger the source the lower the voltage drop across the system once the isolated motor is connected to the alternative source. The larger voltage drop results in a quicker acceleration of the motors on the isolated source. On the other hand, with a weaker source the greater the fault current contribution from the motor bus will result in a lower residual voltage on the motor bus once the fault is cleared. A strong source is one that has a source impedance ratio (SIR) 0.5 and a weak source is one that has a SIR 5.0. SIR values of 0.5, 2.5 and 5.0 will be tested.

4. Inertia of the motor and load

The inertia of the load determines how much energy from the rotor the mechanical load or motor can transfer to the motor bus once the motor bus is isolated. The greater the inertia of the motor, the greater the stored energy the motor has. Therefore, since most buses have multiple motors, the motors with the greatest inertias will act as the generators during the time period that the motor bus is isolated. In the simulations, the inertia of the motor loads will be varied for H of 0.527s, 0.725s and 1.15s.

5. Load on the motor

The load on the motor bus will determine how quickly load is dissipated from the rotational energy stored by the motors. Greater loads will cause both the motor bus voltage and frequency to decrease faster once the motor bus is isolated. Therefore, a heavily loaded motor bus will lower the possibility of a successful in phase motor bus transfer. The load on the motors will be varied as follows: 0.25 p.u., 0.5 p.u., and 0.75 p.u.

6. Breaker closing time

The speed of the breaker greatly affects the probability the voltages will not be in-phase for the in-phase transfer. In order to observe this probability, different closing times must be accounted for. Moreover, if the motor bus is heavily loaded there will be a greater probability that the voltage will not be in-phase. To model a varied closing time a lower, middle, and upper closing time will be used. The values for these closing times are 16.67ms, 33ms, 50ms, and 67ms.

7. Sequence of Events

A fault is introduced to the power system in order to determine the performance of the in-phase motor bus transfer logic. The fault is cleared and the motor bus is isolated from all power sources. Once the motor bus is isolated and the in-phase motor bus transfer logic is enabled to transfer the isolated motor bus to the alternative power source. The performance of the logic is evaluated after a successful transfer by recording the transient torque developed by the motor before the fault, during the fault, and immediately after the motor bus has been transferred.

VII. Transient Test Case

In order to test the effects of the different operating conditions discussed before, transient test cases will be performed in the simulator. This allows for an in-depth analysis of motor bus transfer to verify that it meets the specifications. Numerous tests will be done with all combinations of the operating conditions from Section VI. Example plots for before the fault, during the fault, and when the motor bus is connected to the alternative power source are included below to demonstrate data collected. The developed motor torques (Motors 1, 2 and 3) can be found from plots such as the one in Fig. 4. Second, Fig. 5 provides the related voltage of the motors (a) frequency of the motor bus (b) and alternative source voltage (c) during these same conditions. These two plots allow for an analysis of the motors' peak torques, voltages, and frequency throughout the transient conditions. The torques and minimum frequency were recorded in tables and comparisons can be made to verify if the transfer meets requirements.

VIII. Single Line to Ground Fault Analysis

The following observations can be made with respect to single line to ground faults with non-zero fault resistance. The higher the SIR value (i.e., the weaker the source becomes), the greater the torque developed by the motors during the fault. The reason for this increase in torque will be explained with Fig. 6 [7], [8]. The stronger the source the larger fault current contributed by the external source I_{SOURCE}, and this results in a larger voltage drop V_{FAULT} across the fault resistance R_F. This larger voltage results in a smaller voltage difference between the motor bus and the fault point, resulting in a smaller current contribution I_{M_B} from the motor bus.

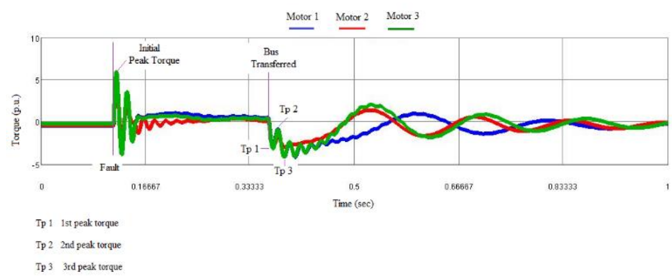

Figure 4: Motor torques developed before the fault, once the bus has been transferred, and after it has been transferred.

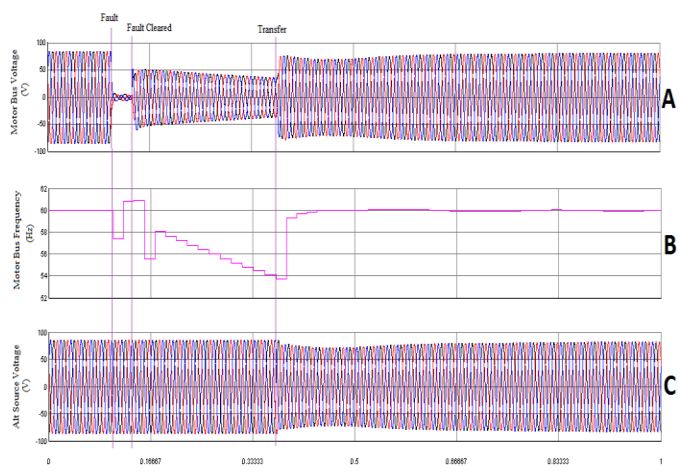

Figure 5: Motor waveforms A.) Motor bus voltage B.) Motor bus frequency C.) Alternative source voltage

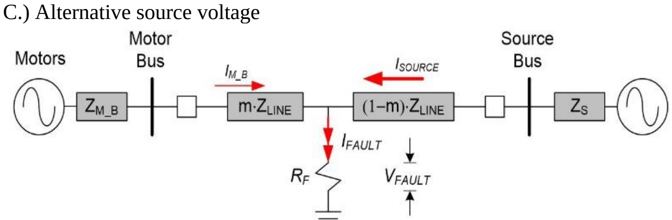

Figure 6: Single line to ground fault configuration

IX. SUMMARY OF RESULTS

1) Test Case 1: Strong Source

Table 3 provides the results for Case I. A Single Line to Ground fault (SLG) was initiated on one of the buses. In this case typical values were used with the exception that the facility is connected to a strong source. It can be noted that the peak fault torque is 2.25 p.u. and the peak close torque on any motor is 5.17 p.u. which meets the criteria.

Table 3: Case 1: Strong SIR

Fault Duration (ms)	Inertia Constant (H) (seconds)	Source Impedance Ratio (SIR)
33	M1 = 1.15 M2 = 0.75 M3 = 0.527	0.5

Load on Bus (MVA)	Speed of Breaker Reclose (ms)	Shunt Capacitor bank (In/Out)
3MVA (0.3 p.u.)	33 (2 cycles)	In (120 kVAR)

Peak Fault Torque	2.25 p.u.
Relcose Torque	-4.24 p.u. -2.05 p.u. -5.17 p.u.
Reclose Frequency and Voltage (motor bus)	51.84 Hz 0.780 kV
Steady State Voltage	1.318 kV (99.2%)
Meet ITI specifications	YES

2) Test Case 2: Strong Source and Heavily Loaded Bus

Table 4 is a case where the load on the bus was much greater, 6 MVA along with a slower reclose (3 cycles). Secondly, the shunt capacitor for voltage support was taken offline to see the effects of the voltage on the motor bus. Note that the reclose torques are lower in this case, but the fault torque is 5.7 p.u.

Table 4: Case 2: Strong SIR and Heavily Loaded Bus

Fault Duration (ms)	Inertia Constant (H) (seconds)	Source Impedance Ratio
33	M1 = 1.15 M2 = 0.75 M3 = 0.527	0.5

Load on Bus (MVA)	Speed of Breaker Reclose (ms)	Shunt Capacitor bank (In/Out)
6MVA (0.3 p.u.)	50 (3 cycles)	out (120 kVAR)

Peak Fault Torque	5.7 p.u.
Relcose Torque	-3.28 p.u. -0.4 p.u. -3.65 p.u.
Reclose Frequency and Voltage (motor bus)	52.7 Hz 0.4 kV
Steady State Voltage	1.296 kV (97.6%)
Meet ITI specifications	YES

3) Test Case 4: Weak SIR and Large Inertia Motors

Lastly, Table 5 shows the results for case 4, where the inertia constants (H) of all the motors were all adjusted to the maximum value of 1.15 seconds. This case has the worst case peak fault torque of 6.0 p.u.

Table 5: Case 4: Weak source and high inertia motors

Fault Duration (ms)	Inertia Constant (H) (seconds)	Source Impedance Ratio
33	M1 = 1.15 M2 = 1.15 M3 = 1.15	0.5

Load on Bus (MVA)	Speed of Breaker Reclose (ms)	Shunt Capacitor bank (In/Out)
3.0 MVA (0.3 p.u.)	33 (3 cycles)	In (120 kVAR)

Peak Fault Torque	6.0 p.u.
Relcose Torque	-2.86 p.u. -0.56 p.u. -3.93 p.u.
Reclose Frequency and Voltage (motor bus)	54.2 Hz 0.595 kV
Steady State Voltage	1.318 kV (99.2%)
Meet ITI specifications	YES

X. CONCLUSIONS

Industrial and mining facilities require motor bus transfer schemes to keep critical processes going in the event of one of the supply sources becoming unavailable. With current methods multiple studies and tests need to be undertaken to ensure a successful bus transfer before a motor bus transfer scheme is put into service. This paper presented a method whereby an in-phase motor bus transfer scheme can be taken into service without requiring any studies or tests. The only information required is the closing time of the bus coupler breaker (transfer breaker), name plate data from the motor with the highest inertia, and the current measurement from this motor during the isolation period (this current measurement is usually available from the motor protection CT's). The proposed method calculates the instant when the closing signal to the bus coupler breaker is sent, taking the closing time of the breaker mechanism into consideration such that the contacts of the bus coupler breaker close at the instant when the voltages behind the transient impedance of the motor and the alternative power source are in perfect synchronism (in-phase). Having the circuit breaker contacts close when the two voltages are in perfect synchronism with each other results in the lowest possible transient airgap torque being developed by the motors following the transfer of the motor bus.

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