

## A Modern Automatic Bus Transfer Scheme

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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 is proposed which includes the development of a new algorithm for determining the type of bus transfer required and the realization of the scheme by using modern protection devices and intra-substation communication facilities.

**Keywords:** Automatic bus transfer, fast bus transfer, IEDs, residual voltage transfer.

### 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]. In this paper, the bus transfer schemes adopted by industries such as slow transfer, in-phase transfer, fast bus transfer and residual voltage transfer methods are critically analyzed. The different bus configurations used in industrial plants, process plants and nuclear plants are provided along with their transfer practices. A modern automatic high speed bus transfer method is presented in this paper using a new algorithm to estimate the residual voltage decay time of the motor bus and the automatic bus transfer scheme realization using modern IEDs and intra-substation communications based on peer-peer communications.

### 2. BUS TRANSFER CONFIGURATIONS

Bus configurations vary with requirements in different plants. The most widely used three configurations are explained in this section [2]. These configurations are used in thermal power plants, process plants and in nuclear power plants.

#### 2.1. Type I bus configuration

A typical station auxiliary system for thermal power generating stations is shown in Fig. 1. This type of configuration is also known as Main-Main bus configuration. This type of configuration is employed to service a single motor bus from two different sources. The normal source (NS) feeds the motor bus through the normal source breaker (NSB), while the alternate source (AS) feeds the motor bus through the alternate source breaker (ASB). Start-up and shutdown power is provided from the alternate source when the main generator is off-line. The station service load is connected to the alternate source during these conditions. The loads include the boiler feed pumps, forced draft fans, induced draft fans, cooling water pumps etc. Once the generator is connected to the system, the station service loads are transferred to the unit auxiliary transformer (UAT), which is connected to the normal source. When the unit is shutdown, the loads previously transferred to the normal source must be transferred to the alternate source. This transfer can be done either manually or automatically. Manual transfers are done during planned start-ups and shutdowns. The automatic bus transfer scheme (ABTS) is preferred because it keeps the dead time of the motors to a minimum. Dead time is the time the motor is in de-energized condition. This type of transfer is also known as station-to-unit transfer in thermal power plants.

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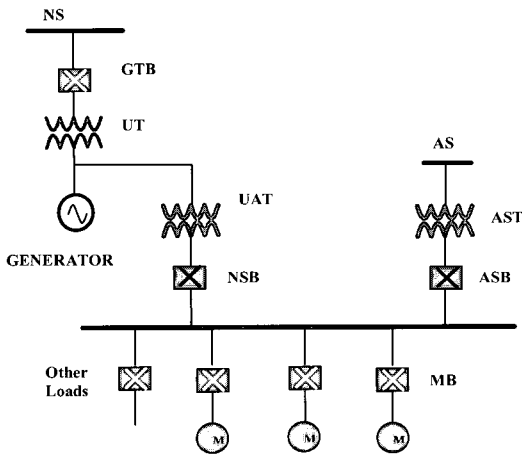


Fig. 1. Type I bus configuration used in thermal plants.

2.2. Type II bus configuration

A typical bus configuration used in process plants like chemical, petroleum, paper mills and steel rolling mills are shown in Fig 2. In this type of bus configuration there are two sources, S1 and S2 each feeding to their respective motor loads. The two sources are tied by means of a tie breaker (TB), which is normally open. Source 1 is connected to its motor load through a station transformer (ST1) and station breaker (SB1) and similarly Source 2 is connected to its motor load through a station transformer (ST2) and station breaker (SB2). Depending on the tie breaker position different operating scenario is possible. The normal operation is performed by keeping the tie breaker open where each source feeds its respective loads. Under emergency condition, which might be due to a fault in the ST1 or in the utility incomer, the loads are transferred to the other source by closing the tie breaker and opening SB1 and vice versa. In process plants also, both manual and automatic transfer schemes are performed. Manual transfer schemes are employed during planned start-up and shutdown of the process. The bus transfer can be accomplished in either break-then-make (open transition) or make-then-break (closed transition) mode.

2.3. Type III bus configuration

Nuclear power plants employ four different bus configurations [3]. Two of the most widely used bus configurations in North America are explained here. There are two types of loads being serviced in nuclear power plants, the class 1E loads and the balance-of-plant loads. The class 1E loads are the loads essential for reactor shutdown, containment isolation, reactor core cooling and containment heat removal. The rest of the loads are called the balance-of-plant loads. Depending on how these loads are fed, the bus configuration changes.

In the first configuration, both the class 1E and balance-of-plant (BOP) loads are normally fed from the

main generator through the unit auxiliary transformer (UAT). When the normal power fails, the class 1E loads and the BOP loads are transferred to an alternate source of power through a station start-up transformer (SST). This bus configuration is shown in Fig 3.

In the other type of configuration the class 1E loads are fed from an alternate source of power through the station service transformers (SSTs) with a provision to transfer them to yet another alternate source of power in case of emergencies. The BOP loads are normally fed through main generator through the UAT as shown in the Fig 4.

Each of the above configurations poses its own complexity when the buses are to be transferred under emergency conditions to an alternate source of power. The important requirement of any automatic bus transfer scheme is the reliable and faster recovery of power

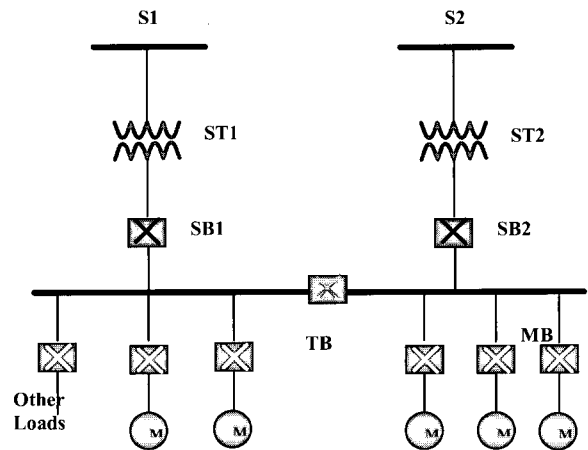


Fig. 2. Type II configuration used in industrial plants.

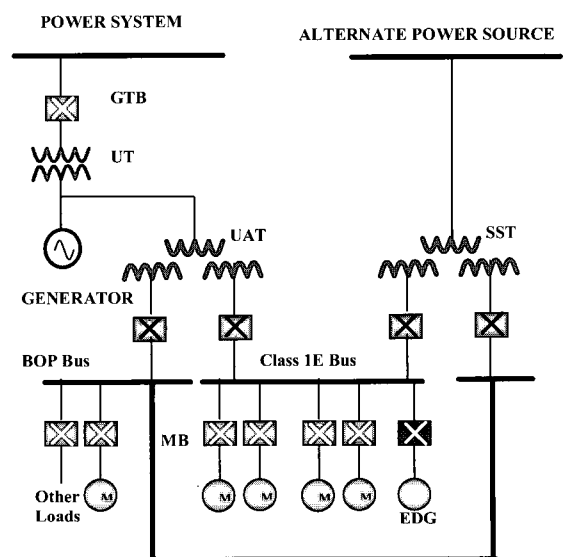


Fig. 3. Nuclear power plant bus configuration in which all auxiliary loads are normally fed from main generator through UATs.

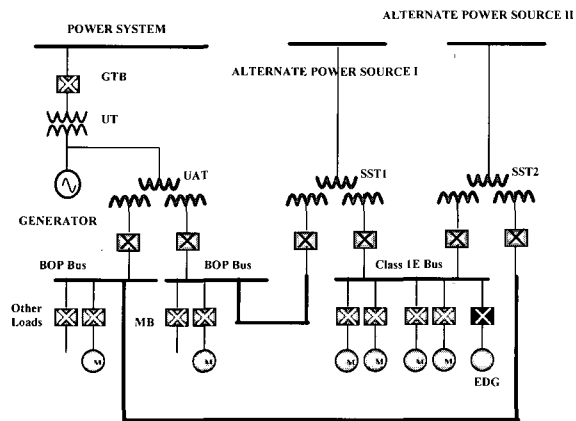


Fig. 4. Nuclear power plant bus configuration in which the class 1E loads are normally fed from a separate source.

to the loads keeping the dead time as low as possible. But the bus transfer practices are compounded by the unique voltage decay and phase angle characteristics associated with each motor bus. This is due to different motors of various ratings and inertia constants, motors fed from starters and from different grounding practices employed [4].

### 3. SPIN-DOWN CHARACTERISTICS OF A MOTOR BUS

On an auxiliary system the loads are mainly induction motors. When an induction motor is disconnected from the source a self-generated voltage known as residual voltage appears at the terminals of the motor [5]. Three important parameters, which are crucial from a bus transfer point of view, are the magnitude of the residual voltage, decay time and the associated phase angle of the residual voltage. The magnitude of the residual voltage decays due to the decay of the trapped fluxes in the air gap of the induction motor. The decay time is governed by the rotor open circuit time constant, which can be obtained from the equivalent circuit of an induction motor. The phase angle of the residual voltage changes with respect to the nominal frequency of the incoming source (50 Hz or 60 Hz). The phase angle change is dictated by the initial load on the motor and by the combined inertia of the motor and the driven load.

In a typical bus system, there may be several motors of widely different ratings. When the bus is disconnected; the large motors with high inertia loads will act as induction generators supplying power to small motors. The total bus voltage will have a complex average response such that the voltage will decay faster than the voltage of the largest individual motor and slower than for a single small motor. An important challenge is the estimation of the open circuit time constant (or the decay constant) of the motor bus terminal voltage for the combined motors. The typical

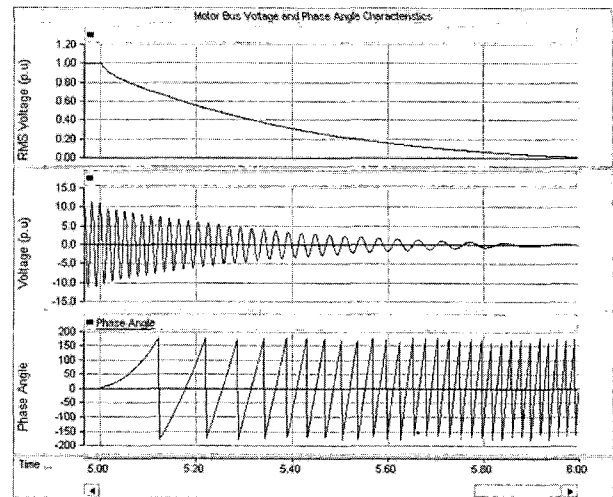


Fig. 5. Typical spin-down characteristics of a motor bus

spin-down characteristics is shown in Fig 5. The motor bus, which comprises of five different induction motors of different ratings and loads, was disconnected at five seconds. The spin-down characteristics show the voltage decay and the phase angle slip with respect to the alternate bus. The motor bus voltage completely decays to zero at around 6 second.

The type of transfer depends on the point on the decay curve where the motor bus is transferred to an alternate source power. Each type of bus transfer has its unique merits and demerits and presents its own level of complexity while implementing it. A successful implementation of a bus transfer scheme depends on the proper analysis of the spin-down characteristics associated with each plant for different loading conditions. When the motor bus is reclosed on to an alternate source of power it is important to study the transient torques and its impact on the motors due to reacceleration. The rotating masses of a motor/load system, connected by elastic shafts, constitute a torsionally responsive mechanical system that is excited by the transient motor torque produced during reclosure [5,6]. This torque contains components at several frequencies, including power system frequency and slip frequency. This can result in either attenuation or amplification of torques at the motor/load shafts. It is therefore, recommended that the electromechanical interactions of the motor, the driven equipment, and the power system be studied for any system where fast transfer or reclosure is used.

### 4. CRITERION FOR SUCCESSFUL TRANSFER

- A successful bus transfer should not subject auxiliary system components to "excessive duty" and should result in safe shutdown or continued operation of the plant.
- The majority of the electric drives used in a power generating station are squirrel cage induction

motors. Importance should be attached to their performance during bus transfer. Two parameters, which should be evaluated, are the switching duty and reacceleration.

- When the auxiliary loads are transferred from the normal source to the alternate source, a large current surge through the SSTs results. Care has to be exercised as to not to subject the station service transformer inrush more than the manufacturer specified limit.
- The final criterion important in evaluating the performance of a bus transfer scheme is the ability of the auxiliary system to maintain or restore process requirements critical for safe shutdown and is the most difficult to define quantitatively. The most important step here is the proper selection of the loads to transfer to the alternate bus[6].

## 5. BUS TRANSFER METHODS

In this section a brief overview of the type of transfer schemes available to transfer auxiliary loads is provided. Bus transfers are of the following types: residual voltage transfer, slow transfer, in-phase transfer, parallel transfer and fast transfer.

### 5.1. Residual voltage transfer

The vast majority of the bus transfer systems in use are of the residual voltage type [1]. In this type of transfer, the auxiliary loads are transferred once the motor residual voltage reaches a value, low enough not to harm the motors connected to the bus. Typically residual voltage transfers are done at 25 to 30% of the rated voltage, irrespective of the phase angle of the motor bus.

#### *Advantages*

Relay and control equipment to implement the transfer scheme is relatively uncomplicated with an accompanying high dependability of correct operations. Most auxiliary systems can be successfully transferred using a residual voltage transfer scheme.

#### *Disadvantages*

Residual voltage transfer is essentially risk free, but usually so slow, it interrupts plant operations. Also, in majority of the cases, motors cannot be reaccelerated simultaneously following such a transfer as their speeds have fallen so low that in-rush currents approach motor locked rotor values and stalling would occur due to depressed voltage. As a result most residual voltage transfer schemes provide for re-accelerating only those drives necessary for a safe shutdown. In some cases, critical drives are restarted in staggered blocks so that full plant operations may not be re-established for 1 to 5 minutes, usually resulting in severe plant upsets. This type of scheme requires shedding of loads connected to the motor bus.

### 5.2. Slow transfer

A variation of this scheme is a fixed time delay transfer in which an intentional time delay is used instead of voltage supervision. This method is not widely used. Time taken is too long and can severely upset plant process. This method will not self adjust to different bus decay characteristics caused by different bus loading. Generally some motor loads are shed to reduce inrush currents.

### 5.3. In-phase transfer

The basic principle behind this scheme is to close the alternate source breaker when the bus residual voltage phase angle is in-phase with the phase angle of the alternate source voltage. To achieve this, a phase angle relay, which can predict the in-phase condition in advance of alternate source breaker closing time, is required. The relay functions similar to a synchronizer for synchronizing a main generator to the system and is sometimes referred to as a synchronous transfer. In-phase transfer minimizes the resultant V/Hz difference between the bus voltage and the start-up source. This is in contrast to the residual voltage transfer, which can allow closure even at 180 degrees.

#### *Disadvantage*

This type of transfer creates serious problems, when bus transfer is initiated during the time, the main source transformer experiences a fault on its side. Momentary paralleling under this situation leads to the alternate source feeding to the fault resulting in the violation of the short time withstand rating of the bus components. In phase transfer can be used successfully on systems, which exhibit a slow to moderate rate-of-change in phase angle.

### 5.4. Fast transfer

The basic philosophy behind fast transfer is to transfer the auxiliary bus as fast as possible keeping the time the loads disconnected from either source of power to a minimum. Fast bus transfer is of two types; Sequential transfer and Simultaneous transfer.

#### 5.4.1 Sequential fast bus transfer

In this type of transfer a "b" or early "b" contact of the main source breaker is used to initiate closing of the incoming source breaker. This approach provides increased security, since the bus has been disconnected from the normal source prior to the alternate source breaker closing. Bus dead time of 5 to 10 cycles is normally encountered with this type of transfer.

#### 5.4.2 Simultaneous transfer

In simultaneous bus transfer, both the main and the alternate source breakers are initiated at the same time. This limits the dead time to one or two cycles

typically. Prior to paralleling the two sources, it is generally ensured that both the sources are approximately in phase to minimize electrical and mechanical transients that can damage the equipments.

*Disadvantage*

Failure of the main source breaker to open will result in paralleling the two sources and if out of phase will result in equipment damage. This type of transfer is not possible when the main source is lost due to an electrical fault or abnormal condition.

The zones of each bus transfer along with their time, phase and magnitude requirement is shown in the Fig 6.

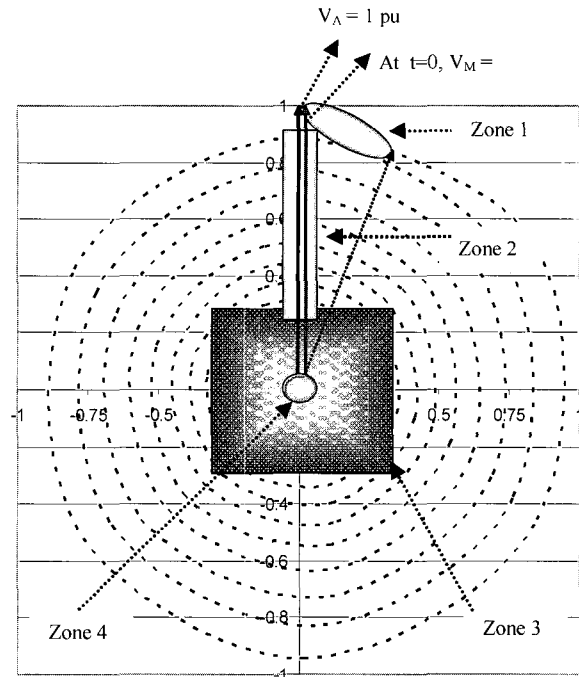
**6. A MODERN HIGH SPEED BUS TRANSFER SCHEME**

Conventionally an automatic bus transfer scheme is developed using electro-mechanical relays and solid state relays with a lot of hardwires connected between them for electrical interlocks [7]. A new modern high speed bus transfer scheme is proposed in this paper using the latest IEDs, intra substation communication facilities and by the development of a new algorithm, which can estimate the residual voltage decay constant of the motor bus for automatically predicting the type of bus transfer under emergency conditions. The algorithm was tested by simulating bus transfers of various configurations, using an electromagnetic transient program, EMTDC/PSCAD.

6.1. Algorithm to estimate motor bus decay constant

A new algorithm has been developed to estimate the residual voltage decay constant of the motor bus [8]. The algorithm requires two sets of digital orthogonal filters. One set of filters tuned to the fundamental frequency and the other tuned to a higher order harmonic not present in the input signal. The filters used are full cycle DFT filters. The sampling frequency used is 3840 Hz. The decay constant of the motor is estimated in approximately one cycle after the motor has been de-energized. Based on the time constant estimation, the value of the tie- breaker closing time and the rate of change of slip, the algorithm will determine the type of transfer feasible. As has been mentioned earlier in this paper, the process of transfer is dependent on so many factors; the residual voltage decay constant of the motor bus, type of loads present in the motor bus, criticalities of the loads and the type of bus transfer practice employed at various plants and industries. Fig 7 shows the estimation of the motor bus residual voltage using the proposed algorithm for the configuration shown in Fig 1. The motor bus is de-energized at time  $t=10$  cycles. From the Fig 7 it is evident that the proposed technique is able to exactly follow the decay voltage from the 11th cycle. The decay constant of the motor bus residual voltage is 2 seconds. The estimated

time constant by the proposed algorithm is 1.98 seconds. The margin of error is 1 %. The frequency of the signal is assumed to be constant for the first two cycle of the decay. A frequency-tracking algorithm is used to measure the change in frequency during the decay. Thereafter, the rate of change of slip is estimated to check the deviation of the motor bus voltage angle from the alternate source voltage phase.



Zone 1 – Fast Bus Transfer Time: < 8 cycles Phase: < 30° Magnitude: > 0.9 p.u.	Zone 2 In-Phase Transfer Time: 8 cycles to 50 cycles -10° < Phase < 10° Magnitude: > 0.33 p.u.
Zone 3 Residual Voltage Transfer Time: > 50 cycles (varies) Phase : Irrelevant	Zone 4 Dead Transfer Time: 100 - 150 cycles (varies) Phase : Irrelevant

Fig. 6. Different bus transfer zones based on motor bus decay characteristics.

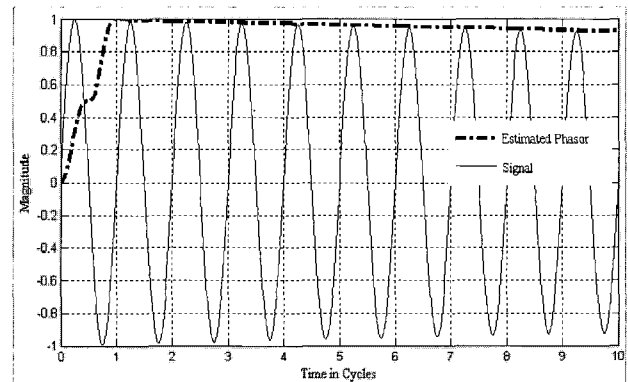


Fig. 7. Estimation of the motor bus voltage using the proposed method.

### 7. EMTDC/PCAD SIMULATION RESULTS

#### 7.1. Case 1

Thermal plants auxiliary buses are characterized by the presence of high inertia fan loads such as forced draft and induced draft fans, and low inertia pump loads such as boiler feed pumps, cooling water pumps etc. The spin down characteristics of 200 MW thermal units auxiliary bus is shown in Fig 8. The system at the time of tripping was lightly loaded. It can be observed from the Fig 8 that due to high inertia characteristics of the motor bus, the bus voltage and phase difference decayed gradually. The difference between the alternate source voltage and the motor bus residual voltage known as the delta voltage is estimated to check the voltage level for bus transfer. It can be seen from the figure that it takes 220 msec for the motor bus voltage to decay to 90% of the initial value and 140 msec to be more than 30 degree out of

synchronism with the alternate source.

For this condition, the algorithm finds that a fast bus transfer is possible for a safe and smooth bus transfer operation with no interruption to the unit auxiliaries. Fig. 9 shows the sequential fast bus transfer initiation with the proposed algorithm. It can be seen that it takes approximately five cycles for the entire operation to take place, a cycle and quarter for the algorithm to detect the contingency and three cycles for the alternate source breaker to close. The total dead time was approximately 5 cycles, which is within the limit prescribed for the fast bus transfer.

#### 7.2. Case 2

A second configuration was chosen to prove that it is not always possible to have fast bus transfer. A 10 MW unit process plant was taken to demonstrate this. The auxiliary bus of the process plant consists of significant amount of low inertia HV compressor load

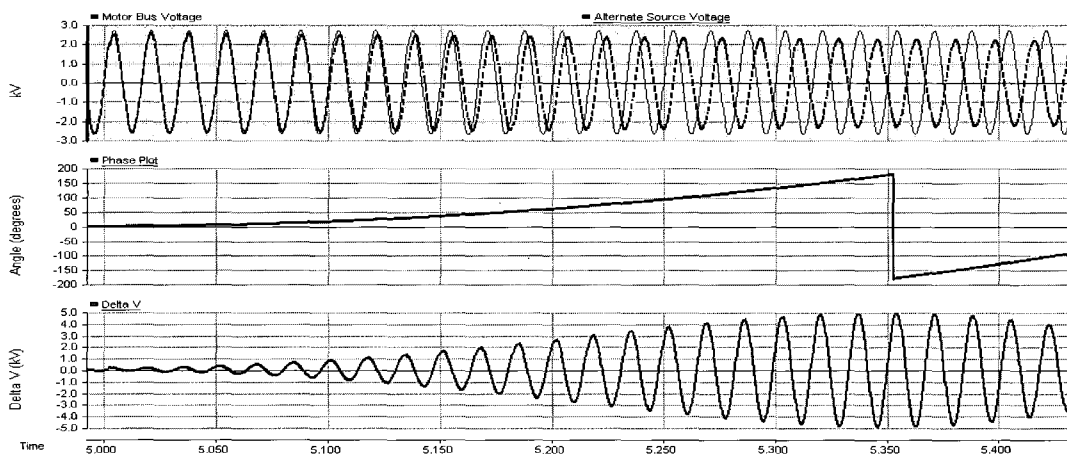


Fig. 8. Spin-down characteristics of a high inertia auxiliary bus.

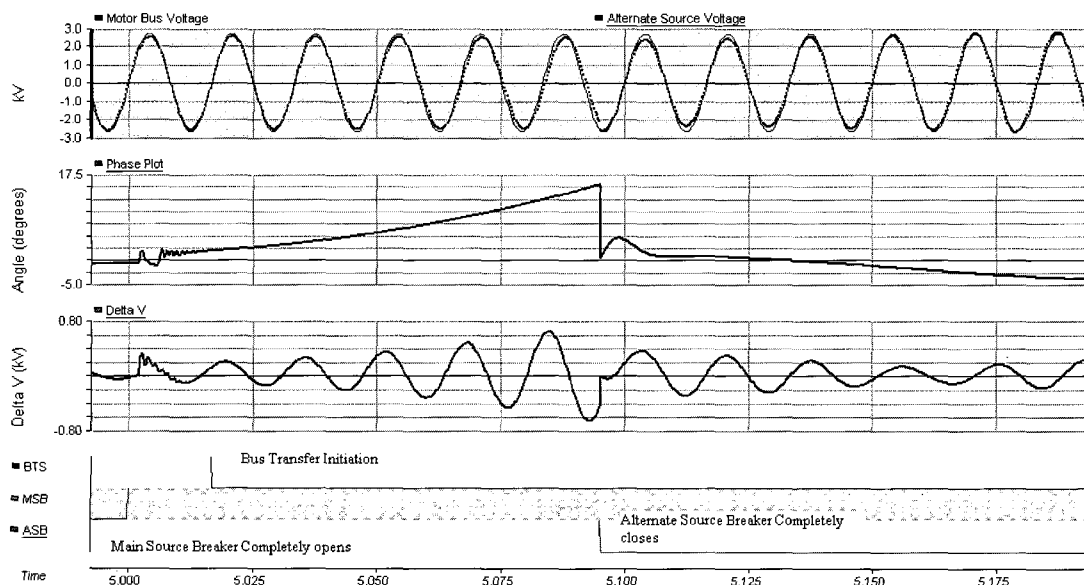


Fig. 9. High speed bus transfer of the thermal unit auxiliary.

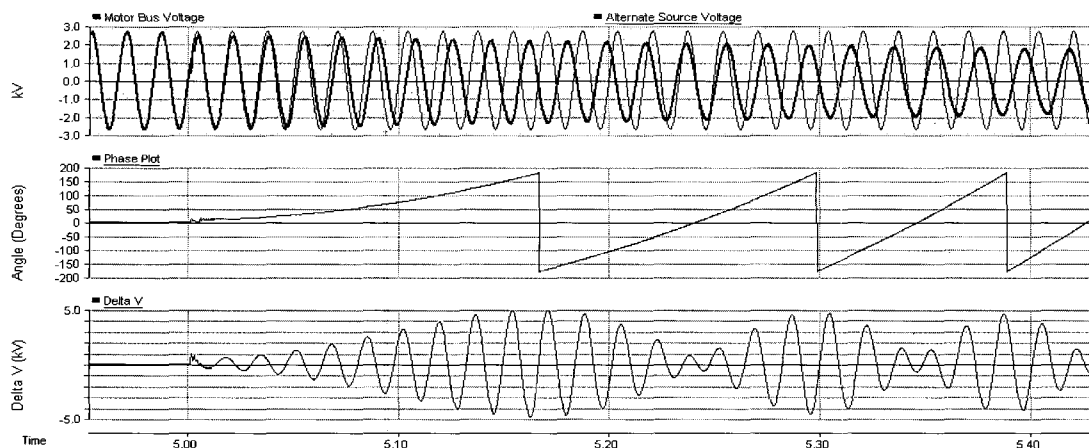


Fig. 10. Spin-down characteristics of a low inertia auxiliary bus of a process plant.

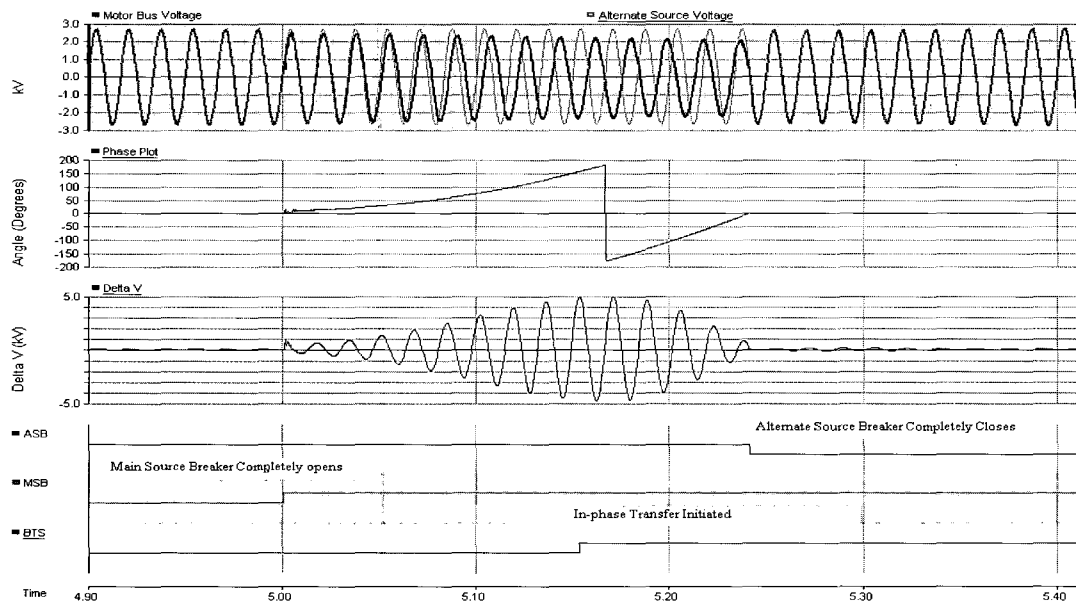


Fig. 11. In-phase transfer process of an industrial process plant.

along with other HV and LV pump, fan, agitators and other motor loads. Because of low inertia loads it can be observed from Fig 10 that there is a brisk fall in the bus frequency at the motor bus as shown by the spin-down characteristics of the motor bus. The algorithm determined that a fast bus transfer under this condition is not possible, as the bus phase drifts close to 60 degree from the alternate source bus in about 5cycles. The normal threshold for fast bus transfer is a phase drift of not more than 30 degree within 6 cycles and a voltage limit of 90%. Approximately the slip is 12 degrees/cycle for this case. Once fast bus transfer is not possible as determined by the algorithm, the next level of transfer is the In-phase transfer. The algorithm waits for the next in phase condition with the alternate source bus, where the difference in phase between the alternate source bus and motor bus should not exceed  $\pm 10$  degrees. The algorithm calculates the occurrence of the next in phase condition based on the time

constant estimation and gives a closing signal to the alternate breaker 4 cycles before the in-phase condition happens. The in phase condition happens at around 220 – 240 msec as estimated by the algorithm. Therefore the closing command to the breaker is given at 153.2 msec. The sequence of the in-phase transfer operation is shown in Fig 11.

## 8. AUTOMATIC BUS TRANSFER SCHEME USING IEDS AND PEER-PEER COMMUNICATION

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 [9,10]. The following are some of the key elements, which need to be taken into consideration for a typical bus transfer scheme;

- Trip circuit supervision of the alternate source breaker and normal source breaker
- Alternate source breaker and normal source breaker status (52aNSB, 52bNSB, 52aASB, 52bASB)
- Fuse failure detection of the potential transformers of alternate source bus, motor bus and main source bus.
- Alternate source and Main source over current detection
- Healthiness of the voltage and frequency of the alternate source

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, 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. A comparison of conventional automatic transfer scheme and modern scheme is shown in Figs. 12 and 13. Fig. 12 shows the conventional methods where there is a need to have separate relays for each function at each bus and significant hardwired electrical connection to the bus transfer panel. Fig. 13 shows the modern bus transfer relay, which can be accomplished with a single IED and its peer-peer communication facility with other IEDs through a station communication bus.

9. CONCLUSION

An overview about different bus transfer methods and their practices was presented in this paper. A new algorithm has been used to estimate the residual voltage decay constant of the motor bus to determine accurately the type of bus transfer possible. Two cases simulated using EMTDC/PSCAD was presented in this paper explaining how different operating conditions determine the type of transfer. Where it is possible to have a fast bus transfer the algorithm Effectively transfers the loads to alternate bus in a approximately 5 cycles, which includes the breaker closing time. It also accurately calculates the in-phase condition well in advance to initiate an in-phase

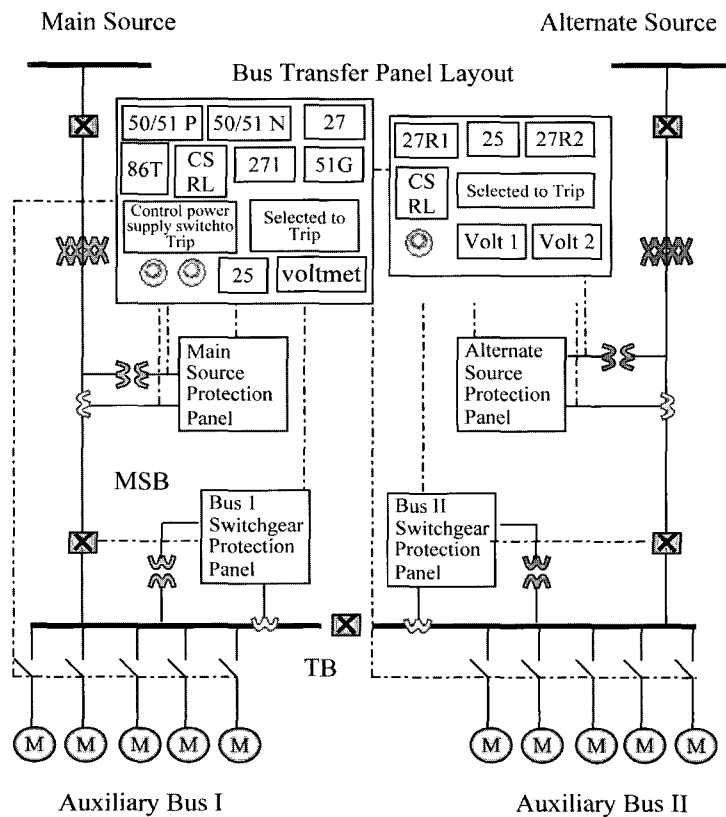


Fig. 12. Typical panel arrangement for conventional bus transfer schemes.



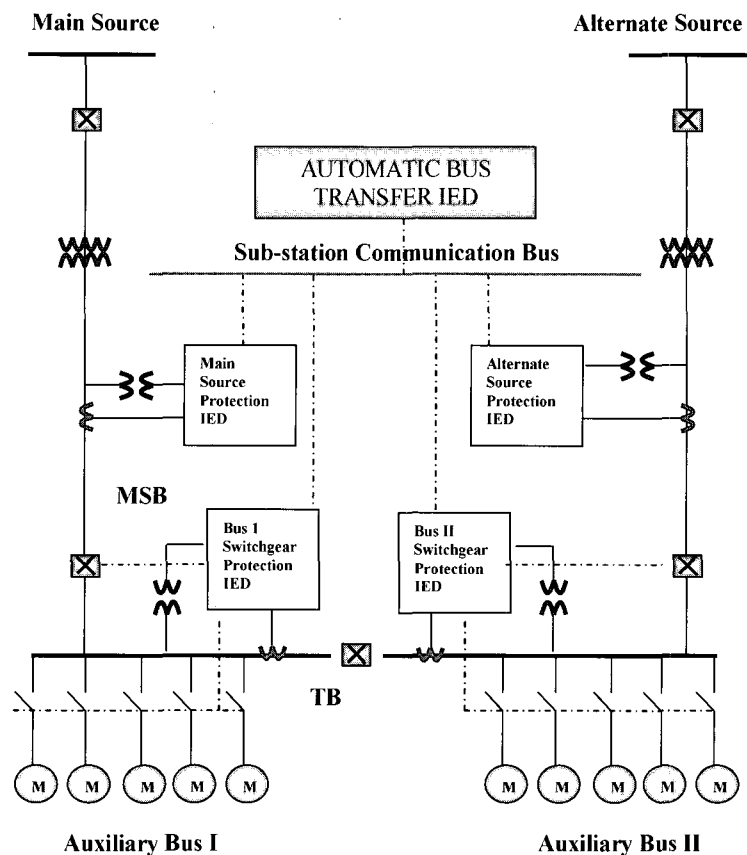


Fig. 13. An automatic bus transfer scheme using modern IEDs and intra-substation communication.

transfer as demonstrated by case 2. The realization of the automatic bus transfer scheme using modern IEDs and intra-substation communications was also presented in this paper.

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