BUS TRANSFER PRACTICES AT NUCLEAR PLANTS

Subinoy Mazumdar
Member

Matthew Chiramal

United States Nuclear Regulatory Commission
Washington, D.C. 20555

Abstract - The dominant trend in U.S. nuclear plants is to use sequential (break-before-make) fast bus transfers. Our study indicates that there have been at least 54 bus transfer failures at U.S. nuclear plants between 1985 and 1989. This paper covers an analysis of the lessons learned from these failures and compares the alternate designs and practices that can improve bus transfer practices prevalent in the United States.

INTRODUCTION

Evaluation of operating experiences at nuclear plants is an important function of the United States Nuclear Regulatory Commission (NRC). Following the requirements of the Code of Federal Regulations all licensees of nuclear plants in the USA submit all reportable events to the US NRC in prescribed licensee event reports (LERs). Our search through the data bank of all LERs between 1985 and 1989 identified 54 events involving failures of bus transfers to take place on demand. This prompted us to do an indepth study on the bus transfer practices prevalent in the USA and abroad; their merits and deficiencies; and the state-of-the-art-development [1]. The salient features of this study are reported in this paper.

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DISCLAIMER

This paper does not represent NRC's position on the subjects covered by this paper.

AUXILIARY POWER DISTRIBUTION SCHEMES

At nuclear plants, the medium voltage (between 2kV and 15kV) auxiliary load buses are provided with feeds from alternate power sources with provision for manual or automatic transfer between the power sources to ensure optimum availability of power to the auxiliary loads. Figures 1 through 4 represent the four basic schemes into which the nuclear plant auxiliary power distribution systems can be categorized from the bus transfer point of view.

In plants that have the auxiliary power distribution system shown in Figure 1, both Class 1E and balance-of-plant (BOP) loads are normally fed from the main generator through the unit auxiliary transformer (UAT). Upon failure of the normal power supply, the auxiliary loads are automatically transferred to the offsite power source through a station startup transformer (SST). In this scheme, on every nuclear unit trip, all auxiliary loads are subjected to bus transfer transients.

In plants that have the auxiliary power distribution system shown in Figure 2, the Class 1E buses are normally fed from the offsite power source through the SSTs with provision for manual (usually) transfer to an alternate offsite power source. The BOP buses are normally powered from the main generator through the UAT as in Figure 1. Thus, in this scheme, the Class 1E loads are not subjected to bus transfer at every unit trip, but the BOP loads are. About 82 percent of the nuclear plants in the USA

Figure 2. Power Plant Distribution Scheme In Which the Class 1E Loads Are Normally Fed From Offsite Power Source Through SSTs.

Figure 4. Power Plant Distribution Scheme in Which All Auxiliary Loads Are Normally Fed From Offsite Power Source Through SSTs.

Figure 1. Power Plant Distribution Scheme in Which All Auxiliary Loads Are Normally Fed From Main Generator Through UAT(s).

Figure 3. Power Plant Distribution Scheme With Generator Circuit Breaker.

ABBREVIATIONS

- MT - Main Stepup Transformer
- G - Main Generator
- UAT - Unit Auxiliary Transformer
- SST - Station Service Transformer
- EDG - Emergency Diesel Generator
- BOP - Balance of Plant Loads

have a power distribution system of either Figure 1 or Figure 2.

The power distribution system shown in Figure 3 is very similar to the system in Figure 1, except that it uses a dedicated generator breaker and needs only one SST. In the event of a unit trip, the generator breaker opens and the power supply to the auxiliary loads continues to be fed from the offsite power source through the main transformer (MT) and the UAT. Thus, this scheme eliminates all bus transfers on unit trips. This scheme is used at eight nuclear plants in the USA and is widely used in Europe.

Another way to avoid bus transfers on unit trips is by using the power distribution system shown in Figure 4. Here both the Class 1E and the BOP loads are normally powered from the offsite power source through the SSTs. This scheme is used at six nuclear plants in the USA and at most plants in France.

BUS TRANSFER SCHEMES

The present-day bus transfer schemes have evolved over the years [3,4]. In early power plants (non-nuclear) manual dead-bus transfers were used. Then, in the early 1950s the residual voltage bus transfer scheme gained popularity. In this scheme, automatic bus transfer takes place when the auxiliary bus voltage decays below 25 percent of its rated voltage.

In the mid-1950s, the sequential automatic fast bus transfer scheme was introduced in the USA. In this break-before-make scheme, a "b" or an early "b" auxiliary contact of the outgoing feeder breaker was used in the closing circuit of the incoming feeder breaker. This ensured that the outgoing circuit breaker would open before the incoming circuit breaker closed and thereby avoided paralleling of the power sources. This scheme usually has a dead band (the time period when both the feeder breakers are in the open position) between 4 and 10 cycles. This scheme is used at all nuclear plants in the USA except for the D. C. Cook Nuclear Plant and the Washington Nuclear Plant 2 (WNP2). In many plants, the residual bus transfer scheme is used as a back up to the sequential bus transfer scheme.

Another type of fast bus transfer scheme is the simultaneous bus transfer scheme in which the operation of both the incoming and the outgoing feeder breakers is initiated at the same time. Usually this scheme has a dead band between 1 and 3 cycles. This scheme is used at D. C. Cook, WNP2, and at all nuclear plants in Sweden and Finland. In this scheme, if the outgoing breaker is slow in opening, or fails to open, then the two sources would be connected in parallel. In the Swedish design, if both sources are paralleled for more than 0.1 seconds, then both closed breakers will be signalled to open [1].

At four nuclear plants in Canada parallel bus transfer has been used in response to generator mechanical trips, turbine trips, and reactor trips. At two of these four plants, simultaneous fast bus transfer initiated by electrical faults in main generator, main transformer, UAT, and SST has also been used, with residual voltage transfer as a backup.

In the United Kingdom, bus transfer operation has been eliminated by connecting the two auxiliary buses through an inductor during normal operation. One of these two buses is normally fed from the offsite power source through the SST and the second bus is fed from the main generator through the UAT. Thus, during normal operation, the two sources are connected in parallel through an inductor. In the event of failure of one of the two power sources, the inductor is bypassed by a normally open device.

ANALYSIS OF BUS TRANSFER FAILURES

The failures associated with bus transfers can be divided into two categories. The first category belongs to cases in which the bus transfers damage the equipment connected to the auxiliary buses, and the second category covers the cases in which the transfer does not take place on demand.

Failures in the first category are caused by the excessive voltage difference in magnitude and phase angle between the auxiliary load bus and the incoming power source. This excessive resultant voltage can cause transient current flows in the system which can damage the transformers,

the switchgear, and the connected loads. ANSI first addressed this issue in 1977 [7] when it recommended limiting the resultant voltage to 1.33 per unit volts per hertz. Subsequently, this criterion has been challenged as the magnitude of the phaser voltage difference between the motor open circuit voltage and the power system voltage cannot be used alone to predict the level of shaft torque which may be experienced upon reconnection of the motor to the power system. [5,6]. The Electric Power Research Institute (EPRI), is studying this issue. At present, in most U.S. nuclear plants, the bus transfer schemes meet this criterion. Our search through our data bank did not find any equipment failures in nuclear plants that can be directly attributed to this cause, although potentially some equipment is stressed in this process. With no equipment failure reported, this appears to be a safe criterion that can be used in bus transfer design.

Failures in the second category defeat the main purpose of providing the bus transfer feature. In most plants, such failures cause the Class 1E loads to rely on emergency diesel generators and the reactor coolant system to rely on natural circulation. Thus, this failure is equivalent to loss of offsite power to the nuclear plant.

Our review of the 54 LERs [1] documenting the failures of bus transfers to take place has identified several factors as root causes: defective design (19 events), equipment failures (15 events), and human errors (5 events) are the leading causes. Of the 19 events with defective design, 12 events are attributable to load dropout due to slow bus transfer. Of the 15 events attributable to equipment failures, 9 events are due to either wrong relay settings caused by lack of setting calculations or to slow speed sync-check relay.

MEASURES TO REDUCE BUS TRANSFER FAILURES

Our study of the bus transfer practices at U.S. nuclear plants indicates wide variation in bus transfer practices and the auxiliary power distribution systems. Some of the following features

are worth considering for improving the existing bus transfer schemes:

1. Minimize Bus Transfer Operations: As indicated earlier, several factors can inhibit a bus transfer. One way to reduce bus transfer failures is to reduce the number of bus transfer operations by adopting an auxiliary power distribution system that has fewer bus transfer operations.

2. Faster Bus Transfer: Although sequential fast bus transfer is widely used in the USA, a simultaneous fast bus transfer scheme is used at two nuclear plants in the USA, two plants in Canada, and all plants in Sweden and Finland.

Evaluation of the EPRI Project Report EL-4286 [4] indicates, that for a nuclear plant, the critical parameters for comparison between the simultaneous and sequential transfer schemes are as shown in Table I.

TABLE I.
COMPARISON OF CRITICAL PARAMETERS
BETWEEN SIMULTANEOUS AND SEQUENTIAL
FAST BUS TRANSFER SCHEMES

PARAMETER (Maximum Value)	SIMULTANEOUS (2-Cycle Deadband)	SEQUENTIAL (6-Cycle Deadband)
Resultant per unit volts per hertz between motor internal voltage and system	0.575	1.828
Motor transient torque per unit on motor basis	3.46	9.36
Motor transient current per unit on motor basis	3.22	9.67

This table indicates that in unsupervised sequential fast bus transfers the connected electrical equipment can be subjected to resultant voltages far in excess of the 1.33 per unit volts per hertz requirement of ANSI C50.41-1982, while in simultaneous transfers the resultant voltage will not exceed even half of this voltage criterion. Broadly speaking, the motor transient

torques and currents are about one-third in simultaneous transfer schemes compared to their values in sequential transfer schemes. Thus, the electrical and mechanical stresses produced in simultaneous bus transfer are far below the stresses produced in sequential bus transfer. Even the present controversy over ANSI C50.41 criteria on resultant voltage is not of any concern in a simultaneous bus transfer scheme.

3. Supervised bus transfer:

The fast bus transfer schemes can be either a supervised or unsupervised type. Our review of the 54 LERs on bus transfer failures indicates:

A. A malfunction of the generator excitation system can cause excessive voltage deviation between the generator terminal and the offsite power system.

B. As demonstrated in Millstone LERs 88-026-03 and 89-030-00 [2] under special operating conditions, the generator voltage and frequency can be substantially different from the offsite power system voltage and frequency at the instant of bus transfer.

C. In certain plants, there may be significant phase shift between the generator voltage and offsite power source, especially when they are not from the same switchyard.

D. A fault or lightning can cause transient system disturbance, in which event, a supervised scheme is the best way to ensure optimum safe bus transfer.

These findings lead to the conclusion that one way of ensuring safe bus transfer under all operational conditions is to use supervised bus transfer schemes that use sync-check relays or microprocessor-based bus transfer systems. In the past, the sync-check relays were of the induction disc type which are much slower than the static sync-check relays developed in the 1980s.

CONCLUSIONS

Although the current rate of bus transfer failures is not alarming it can be substantially reduced by incorporating some of the features mentioned in the paper. Reduction in bus transfer failures at a nuclear plant can lead to an improvement in availability of the plant auxiliary system which has a direct effect on the safe operation of the plant.

REFERENCES

- [1] S. Mazumdar, "Operational Experience on Bus Transfer", US NRC Engineering Evaluation Report AEOD/E90-05, June 1990.
- [2] North East Utilities, Licensee Event Reports, LER 50-422/88-021 and LER 50-422/89-30.
- [3] T. A. Higgins, W. L. Snider, P. L. Young, H. J. Holley, "Bus Transfer Part I-Assessment and Application", Transaction on Energy Conversion, Volume 5, No. 3, September 1990.
- [4] J. C. Appiarius, E. L. Owen, R. M. McCoy, A. Murdock, "Improved Motors for Utility Applications, Volume 2: Bus Transfer Studies," EPRI EL-4286, Volume 2, Project 1763-2, Final Report, October 1986.
- [5] J. S. C. Htsui, "Magnitude, Amplitude and Frequencies of Induction-Motor Air-Gap Transient Torque Through Simultaneous Reclosing With or Without Capacitors, "IEEE Transactions on Power Apparatus and Systems, Volume PAS-104, No. 6, June 1985.
- [6] R. H. Daugherty, "Analysis of Transient Electrical Torques and Shaft Torque in Induction Motors as a Result of Power Supply Disturbance, "IEEE Transactions on Power Apparatus and Systems, Volume PAS-101, No. 8, August 1982.
- [7] American National Standards Institute, Standard for "Polyphase Induction Motors for Power Generating Stations", C50.41-1982.

Subinoy Mazumdar (M'72) was born in Jamshedpur, India on December 26, 1935. He received his B.E. from Bengal Engineering College, Sibpore, India, standing first in Calcutta University; M.E. from City College, New York; Ph.D. from Polytechnic University, Brooklyn, NY, in 1953, 1973, and 1981, respectively, all in electrical engineering.

He has worked for several electrical manufacturing, consulting, and utility companies in India, the U.K., and the USA. In 1989, he joined the Nuclear Regulatory Commission, Washington, D.C., and is currently working on the evaluation of operating experience of nuclear plants. Dr. Mazumdar is a member of the IEEE Power Engineering Society.

Matthew Chiramal was born in Kerala, India on March 22, 1938. He received a BE degree from the Bengal Engineering College, Calcutta University in 1961. He has done graduate work in Nuclear Engineering at the Catholic University of America, Washington, D.C. from 1970 to 1973. He is a Licensed Professional Engineer (Electrical) in the Commonwealth of Massachusetts from 1974.

From 1961 to 1970, he has worked at the Tarapur Atomic Power Station in India. From 1970 to 1977, he worked as a design engineer at various Architect Engineers. In 1977, he joined the Nuclear Regulatory Commission and is currently working on analysis and evaluation of operational experience of nuclear power plants.