

IMPLEMENTATION OF GROUNDING, BONDING, SHIELDING AND POWER SYSTEM IMPROVEMENTS IN FAA SYSTEMS: RELIABILITY ASSESSMENTS OF THE TERMINAL DOPPLER WEATHER RADAR (TDWR)

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Introduction

The safety and efficiency of the National Airspace System (NAS) is critically dependent upon the inherent reliability of the many systems required for its operation. A major impediment to reliability is the frequency at which FAA systems fail due to electrical power interruptions. These failures are most often associated with power system transients that result from the passage of thunderstorms in the vicinity of FAA facilities. In order to improve the reliability of the NAS, the FAA has developed and implemented a program to provide improved Grounding, Bonding, Shielding and Power systems (GBSP) in support of major facilities. This paper reports on the initial program effort, dealing with performance of the Terminal Doppler Weather Radar System (TDWR) and the effects of implementing the GBSP program. The program has resulted in significant improvements in reliability. The evidence for this is provided by correlation studies comparing system failure rates prior to and after implementation of the GBSP [except for the addition of the Site Wide Uninterruptible Power Supply (UPS) system that was installed beginning in August of 1998]. Detailed examination of local cloud to ground lightning activity, as reported by the National Lightning Detection Network, is also used to examine a number of cases at select airports where thunderstorm activity is of high intensity. The results confirm that the current TDWR system is robust to electrical disturbances that are often produced by lightning events in the vicinity of the radar. Note that the case studies relate to the entire GBSP program, including the addition of a new UPS system. Details on this Site Wide UPS system are not included in this paper.

Background

The primary mission of the TDWR is to enhance the safety of air travel through the timely detection and reporting of hazardous wind shear (e.g., microbursts and gust fronts) in and near the terminal approach and departure zones of an airport [1, 2]. Forty-two systems have been commissioned and are fully operational with three more expected to be commissioned by the end of 2001. As part of normal upgrading of its systems, the FAA established a program in 1996 to evaluate the performance of the TDWR systems and recommend modifications that would address any deficiencies. The study identified three areas of concern: mechanical and electrical failures of the antenna drive system; the reliability of the telephone communications link between the TDWR Radar Site and the display functional unit (DFU) that produces and transmits wind data to air traffic control displays; and state-of-art relevancy of the radar product generator (RPG) computer subsystem. Hearsay evidence from numerous controllers and technicians contended that a large fraction of TDWR failures were associated with thunderstorm activity in the vicinity of the airports [3,4]. These appeared to manifest themselves mostly as interruptions to the RPG or loss of communications. Since the primary purpose of the radar is to monitor winds during severe weather conditions such as thunderstorms, the FAA initiated a programmatic effort to reduce the susceptibility of the TDWR to electrical disturbances associated with such thunderstorms. The assessments resulted in a comprehensive approach to improve the reliability of the system. This paper identifies the changes that were implemented in the system and provides a preliminary examination of the benefits derived from these changes. The focus is on the number of

outages reported over a period of three months during the summers of 1996 to 1998. A key element in the analysis includes the correlation of the type and number of outages with lightning activity in the vicinity of the airports and the TDWR systems.

GBSP Program¹

The intent of the GBSP program was to address deficiencies in the performance of the TDWR systems caused by power interruptions and electrical disturbances associated with cloud to ground lightning discharges in the vicinity of airports served by these systems. A secondary benefit was to reduce outages due to other electrical disturbances as well, including those resulting from power surges and outages of commercial power sources that may or not be associated with thunderstorms. The grounding, bonding, shielding and power systems improvements are identified in the following sections.

Power Distribution System

The TDWR system is powered by a three-phase, four wire 208Y/120 V, 150-kVA source with one wire being neutral. At the main service entrance switch, the neutral is connected directly to a grounding electrode in the facility grounding system (Earth Electrode System). A separate ground wire connection is available throughout the electrical system, and, elsewhere throughout the facility, the neutral is isolated from the ground. Commercial power is primary with auxiliary standby power available from an automated (also manual) switching, Engine/Generator (E/G) set. Neutral and ground nodes are also connected together at the E/G grounding plate, mounted on the E/G set.

Grounding Circuit

This section outlines the grounding circuit that was designed to balance the system electrically and reduce the possibility of external electrical

disturbances producing voltage irregularities that can affect the operation of the radar.

The area of greatest concern for grounding insufficiencies was the TDWR Radar Site, consisting of a tower and antenna assembly, radar electronics and telecommunications and engine-generator (E/G) facilities. The latter three subsystems are housed in a single TDWR Building, separated into three rooms – the Radar Equipment Room, the Telco Room and the E/G Room. One side of the Telco Room that separates it from the Radar Equipment Room consists of a heavy-duty wire mesh. In order to minimize the generation of induced voltages associated with transient electrical disturbances arising from lightning discharges at or near the TDWR Radar, a counterpoise grounding system was designed and implemented. This system consists of a sequence of grounding that attempts to achieve balance throughout the entire TDWR Radar Site.

TDWR Building

The Radar Equipment Room configuration consists of two separate multipoint grounding plates plus three ground plates. The two multipoint plates are used for common connection of two banks of symmetrically arranged radar electronics equipment cabinets. One grounding plate serves to provide a common connection to two cabinets containing air conditioning air handling units that serve the Radar Equipment Room. The two radar cabinet multipoint ground plates are tied together through a common connection to the waveguide pallet that supports the radar waveguide and associated equipment; each plate is also separately tied to their own main ground plates, located at two oppositely located entrances to the Radar Equipment Room. The steel entrance doorframes are each connected to their respective nearest main ground plates, unless otherwise noted. The two main ground plates are tied together within the building as well as being independently connected to the exterior counterpoise circuit that surrounds the TDWR Radar Building via underground non-conducting conduits. The air handling grounding plate is independently connected to the external TDWR Building counterpoise. All connections from the Building internal plates to the building counterpoise are routed as directly as possible.

¹ For the purposes of this paper, GBSP refers only to grounding and bonding practices, unless otherwise noted. Grounding is the means by which a common electrical reference point is achieved, and bonding refers to the means of connecting various nodes throughout the grounding system.

The Telco Room includes one ground plate that serves as a common connection for the telephone equipment ground-line, the wire mesh wall separation, three external electrical access conduits and the external doorframe of the Telco Room. One conduit provides external access from the grounding plate to the Building counterpoise, and a second one provides access for the telephone communications cable. The third conduit is a spare.

The E/G Room serves multifunctional needs. In addition to providing housing for the auxiliary power generation E/G set, the Room also houses the main commercial power access (includes power distribution panels and circuit breakers), a transient voltage surge suppressor (TVSS), a mechanical commercial power disconnect switch, an automatic transfer switch (ATS) for transfer of power between commercial and auxiliary E/G power, an electrical heater, an exhaust fan, a temperature sensor, a battery charger, and a propane leak detector and automated propane exhaust fan. The E/G subsystem includes a large intake hood and a large exhaust plenum. The alternator, three-phase neutral (E/G is a separately derived source) and frame and engine generator frame are connected to ground via a multipoint grounding plate on the E/G set. This plate is connected to a main grounding plate that also has connections to the E/G exhaust plenum and the engine block. A second main grounding plate is mounted inside the main service disconnect switch cabinet; it is connected to the main service neutral as well as to the main power entrance and exit conduits, the cabinet itself, the E/G intake hood and the ATS ground plate. The doorframe is connected directly to the E/G intake hood. The ATS cabinet contains a multipoint grounding plate that connects the ATS cabinet and all conduits to the second main grounding plate.

Building Counterpoise

The building grounding counterpoise consists of an electrically closed circuit loop that surrounds the building at a distance of approximately seven feet from the external walls. The cable is made of 4/0 AWG stranded, bare Copper (Cu) cable that is connected with exothermic welds to ¾ in by 10 foot deep Cu-clad steel grounding rods at less than or equal to 20 foot intervals around the building. The loop is electrically completed by exothermic connection at a common ground rod. The Radar

Equipment Room main grounding plates inside the building are connected and exothermically welded to the building counterpoise via 500 MCM Cu cables (insulated black). The air handling grounding plate is exothermically welded and connected to the building counterpoise via 4/0 AWG stranded, insulated Cu cable.

The Telco Room main grounding plate employs a No. 2 AWG Cu stranded wire for connection to the building counterpoise via exothermic weld.

The E/G Room main plates are individually connected to the building counterpoise via 4/0 AWG stranded cable.

The building counterpoise is also connected to conducting elements that reside outside the building. The latter include separate connections to: a common grounding plate for the E/G Room exhaust fan housing, exhaust pipe, exhaust hood and propane leak detector exhaust hood; a common grounding plate for the waveguide, its unistrut support structure and the two antenna conduits; the E/G intake hood; the E/G load bank frame; the propane fuel line; and each of the two A/C compressor frames that are connected separately to the nearest air handler intake hoods. All counterpoise connections are exothermic welds to 4/0 AWG stranded Cu cables that are either crimped to connecting lugs for contact with their respective elements² or pressure clamped to conduits.

The TDWR Building roof includes a metal pole to support an antenna for a WWV radio receiver that provides standardized timing for the radar signals. This pole is separately connected to the building counterpoise via 2/0 AWG stranded bare-Cu cable, terminated at the counterpoise with an exothermic weld.

Tower and Tower Counterpoise

Prior to the grounding upgrade, the TDWR antenna tower included six symmetrically-placed air terminals and one at the apex that were connected to a conducting, closed circuit, bare-Cu peripheral cable. Two bare-Cu down conductors were mounted along the inside of two diametrically

² Note: all connecting lugs are made with a concentric hydraulic (14-ton minimum) crimping tool.

opposite tower legs and connected to a tower counterpoise via exothermic welds. Exothermic welds were also made from the down conductors to each section of the tower at approximately the center of the sections. The additions to this grounding circuit included connecting the lowest stairway section and the four legs of the tower to the tower counterpoise. These connections were made by exothermic weld of 4/0 AWG insulated stranded Cu cable to the legs and the counterpoise. A multipoint grounding plate was also added at the base of the tower to provide a common connection for the waveguide, the waveguide unistrut support structure and the two electrical conduits that contain wiring for energizing and controlling the antenna subsystem. The grounding plate is separately connected to the tower counterpoise by 4/0 AWG, stranded, insulated Cu cable that is exothermically welded to the counterpoise. Lastly, a TVSS was connected to the antenna subsystem's power distribution panel that is used for everything electrical on the tower except the motor drives and RF transmitter and receiver energy.

The tower counterpoise is located at a distance of around 12 feet from the base of the tower. The side adjacent to the TDWR Building is connected to the building counterpoise as a shared, common connection.

Restricted Access Perimeter Fence

The TDWR Site is enclosed by a perimeter fence to restrict access to the radar equipment, facilities, tower and E/G propane storage tank. Depending on the site, the three-phase commercial power transformer is either mounted on a pole that is outside the fence or pad mounted inside. The fence is chain-link type, approximately 10 feet high and supported by 2 in diameter metal fence posts, except for the gateposts that are 3 in. A typical configuration for the fence is 110 X 110 ft with post separations of 10 ft. A #6 AWG stranded bare-Cu wire is woven through the chain link fence at a height of around 5-6 feet and C-clamp connected to every 3rd post that is connected to the counterpoise.

An outer counterpoise was added at a distance of no more than three feet outside the fence. All corner posts are exothermically welded to the corner of the counterpoise with 4/0 AWG stranded bare-Cu cable. Each gatepost is similarly tied to the counterpoise as are every third fence pole.

Connections at distances less than every third post are acceptable in order to accommodate lengths undivisible by three.

The propane gas tank(s) are typically located at a far corner of the perimeter fence. The tank legs and liquid propane line to the E/G Room are connected separately to the outer counterpoise with 4/0 AWG stranded bare-Cu cable.

In order to complete the grounding system and achieve reasonably balanced operation, the perimeter fence counterpoise is connected to the Tower and TDWR Building interconnected counterpoise system at four points. The latter are located at the approximate center of each side of the fence counterpoise circuit, that are then connected to points on the nearest interior shared counterpoise circuit. All these connections are exothermic welds and via 4/0 AWG stranded bare-Cu cable.

Performance Analysis

Criteria for Site Selection

In order to assess the impact on performance of TDWR systems that resulted from the aforementioned modifications associated with the GBSP program, data on system outages were examined for the primary thunderstorm months of June, July and August of 1996, 1997 and 1998. This period covers the transition of the implementation of the first phase of the GBSP program (excludes UPS upgrade), which began with the first site at Washington National Airport (DCA) on January 19, 1997. The remaining 42 sites were upgraded with the GBSP program over a period of just under two years after this date. Since archival reports on outages or failures of FAA systems are initiated only after commissioning of the systems, the analysis was necessarily restricted to those TDWR sites that had been commissioned prior to the summer of 1996. The study was further restricted to those sites that completed installation of the GBSP modifications prior to June 1, 1997. This provided a reasonable basis for assessing the effects of the changes on system reliability via comparisons of 1997 and 1998 data with data from 1996.

The criteria led to the selection of 13 TDWR sites for the reliability analysis. These included: Houston (IAH), Memphis (MEM), Saint Louis

(STL), Kansas City (MCI), Denver (DEN), Atlanta (ATL), Charlotte (CLT), Washington National (DCA), Dallas (DAL), New Orleans (MSY), Tampa (TPA), Miami (MIA) and Dallas-Fort Worth (DFW). This list is given in the order of the commissioning dates of the TDWR radars at these sites. None of these sites had the GBSP modifications implemented during the months of interest in 1996; all but MEM were implemented during 1997; and all were implemented in 1998.

Major TDWR Subsystems

TDWR failures were derived from FAA records at the National Operations Control Center (NOCC) in Herndon, VA. These fell into 11 separate categories with four of these being most appropriate for analysis here. These are the Radar Products Generator (RPG), the communications systems (TELCO), the dual transmitter, receiver and digital signal processor system (TX/RX/DSP) and commercial power (CP) source. Each of these is considered sensitive to electrical disturbances, and the reliability performance of all, but CP, might possibly be influenced by the GBSP implementations. These four categories account for around 71% of all the outages in 1996. Of this, the RPG amounted to approximately 41% of the total.

Failure Rates: 1996 – 1997 -1998

Table 1 shows the failure rates of the four selected categories relative to its value in 1996. Averages are also indicated for comparisons with and without CP. The results demonstrate a significant reduction in outages occurred in '97 and '98 relative to '96 prior to implementation of the GBSP.

Table 1. Relative Failure Rates Of Major TDWR Subsystems And CP, Commercial Power.

FAILURE	'96	'97	'98	'97 /'98
RPG	1.00	0.43	0.53	0.48
TELCO	1.00	0.63	0.50	0.56
TX/RX/DSP	1.00	1.00	0.57	0.79
CP	1.00	1.43	1.43	1.43
AVG W/O CP	1.00	0.69	0.53	0.61
AVG W/ CP	1.00	0.87	0.76	0.82

Weighted data on these same events are illustrated in Table 2. All data in this table are relative to failures of the RPG in 1996. The table shows that, excluding CP, there was an overall reduction in failures of the other three criteria by approximately 47% from the 1996 values. If one includes CP in the data set, this reduction is reduced to 38%. The greatest absolute and relative improvements were associated with the RPG, which exhibited a 52% improvement in reliability. TELCO improved by 18% relative to its 1996 value, and TX/RX/DSP improved by 3%. On the other hand, the CP increased by 8% relative to its value in 1996.

Table 2. Failure Rates Of Major TDWR Subsystems And CP Relative To RPG In 1996.

FAILURE	'96	'97	'98	'97 /'98
RPG	1.00	0.43	0.53	0.48
TELCO	0.40	0.25	0.20	0.22
TX/RX/DSP	0.17	0.17	0.10	0.14
CP	0.17	0.25	0.25	0.25
% W/O CP	100	54	53	53
% W/ CP	100	63	61	62

The effects of the changes in GBSP implemented during the time between the end of the summer of 1996 and the beginning of the summer of 1997 are evident in Tables 1 and 2. Significant software changes were made to the TDWR in 1997 to improve reliability of the RPG's. These changes no doubt contributed to the reduction of failures in the period studied. Thus, it is difficult to attribute observed changes to be solely due to the GBS changes in the system. Another possible major interference in this interpretation is the amount of lightning activity that occurred at the TDWR sites during the time periods considered. If lightning (thunderstorm activity) were exceptionally high during 1996 relative to both 1997 and 1998, this would have to be accounted for through an analysis that includes normalization of the failure rates to lightning activity in the vicinity of each TDWR site. This evaluation is underway and is expected to be completed in the near future.

Case Studies of Thunderstorm Events

Additional empirical evidence to support the above findings was found through a comparison of lightning activity (cloud to ground flashes and rates in the vicinity of the radar within a box out to ± 20 nm from the radar's antenna) with TDWR failure data. National Lightning Data Network (NLDN) records of cloud to ground lightning flashes were examined for all the TDWR sites during the summer months of 1999 and 2000. The greatest lightning activity was in Tampa (TPA), which experienced approximately 25,000 flashes within the vicinity of the Radar during July 2000. During this month, TPA had no reported failures of its TDWR system. Five other high thunderstorm activity sites were identified during this same month of July 2000 – Orlando (MCO), Fort Lauderdale (FLL), West Palm Beach (PBI), Miami (MIA) and Kansas City (MCI). The monthly flash rates at these other sites ranged between 11,000 (MCI) to 19,000 (MCO) flashes per month. Only three of the 21 failures at these sites (includes TPA) correlated with thunderstorm activity.

Additional data were evaluated for other months during the two-year period, namely, June of 1999 and June of 2000. These were selected on the basis of the number of sites, which experienced high lightning activity (over 7,500 per month). Seven sites, not necessarily the same sites although both months included TPA, met these criteria. Combining these two months with the July 2000 case yielded a total of 41 TDWR failures. Only five of these might have been associated with thunderstorm activity as evidenced by lightning flashes occurring within vicinity of the TDWR radar antenna. Note that, for all these results, lightning activity had to precede the failure in time and proceed beyond that time in order to make an association of the failure with lightning.

This examination of the possible association of lightning activity with the failures experienced by the TDWR system indicates that the sensitivity of the system to thunderstorm activity is low, at most accounting for around 12% of all failures during high thunderstorm months.

Conclusions

The results of this investigation demonstrate that significant improvements in the operational performance of the TDWR system occurred following implementation of the FAA's GBSP program that began in late 1996. A detailed description of the grounding, bonding and shielding (GBS) practices that were implemented by the FAA are included. Twelve sites were identified as having been commissioned prior to the summer of 1996 and modified with the grounding, bonding and shielding provisions of the GBSP program prior to the summer of 1997. Another site (MEM) was included in the study, although it did not experience its upgrade until September 1997. The summer thunderstorm months of June, July and August were selected in order to focus the study on situations thought to be most susceptible to electrical disturbances.

The major TDWR subsystems that were considered most susceptible to electrical disturbances were identified as the RPG, TELCO and TX/RX/DSP. Commercial power (CP) was also used, since it contributed significantly to system failures prior to the addition of a UPS system, beginning in August of 1998. Since it would be difficult to discriminate between the effects of implementing the entire GBSP from those of the GBS, the summers of 1996 through 1998 provided the best possible source of data to evaluate and infer results of the GBS implementations (without having to deal with the added complexity of the UPS system on performance reliability). Furthermore, with the limited data available, it is not possible to isolate the definitive contributions of the GBSP program from other changes (e.g., software) that were made to the TDWR system during the 1996-1998 time frame.

Data from the summers of 1996, 1997 and 1998 provided strong indications that the effects of the GBS were highly effective in improving the reliability of the TDWR system. The relative improvements in failure rates amounted to 52% for the RPG, 44% for the TELCO and 21% for the TX/RX/DSP. During the same period the CP caused a 43% increase in its failures (note that this was a major factor in the FAA's decision to add a site-wide UPS component to its TDWR GBSP program). The total overall performance of the

TDWR system (based on the thirteen sites examined and excluding CP) improved by approximately 28%. Unless the summer of 1996 was unusually high in thunderstorm activity, the results strongly support the premise that the FAA's GBS component of its GBSP program has been highly effective in reducing the sensitivity of the TDWR system to electrical disturbances.

A number of case studies, using the NLDN lightning flash data during the summers of 1999 and 2000 and considering all TDWR sites, provided additional support for the previous conclusion, except that these studies included effects of the addition of site-wide UPS systems.

Future studies are underway to examine how lightning activity at all thirteen sites considered here might have affected TDWR performance during the 1996-98 time frame. Of particular interest is the need to resolve whether lightning activity during the summer months of 1996 might have been responsible for the improved differences in TDWR performance reported here.

Note

The content of this paper reflects the views of the authors only and does not represent FAA or USDOT formal policy.

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