Upgrading Digital Fault Recorder Systems

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Introduction

Many of the Digital Fault Recorder (DFR) systems available today have much to offer the oscillographer, with such features as high-speed network-based communication links to the remote DFR systems, event recording at multiple recording speeds, and long-term storage of event records at the remote DFR. Yet, for one to take advantage of these new features significant hardware and software upgrades to the existing DFR system may be required. In some cases, the station's entire DFR system must be replaced.

In the mid-1980s the Southern California Edison Company (SCE) began an aggressive replacement program of their many light-beam oscillographic fault recorders with first generation DFRs. SCE had replaced all of its light-beam recording systems with DFRs within five year's time, and even added DFRs to stations which previously had no fault recorders available. By early 1991, SCE had over sixty substation sites with DFRs installed. Now, in just over ten year's time, SCE is in the midst of a program to replace its first generation DFR systems with the newer technology DFRs offered today. The oscillographers at SCE began to show a keen interest in the many features provided by the newer technology DFRs, but faced the challenge of justifying the replacement of the first generation DFR systems.

Beginning in the year 2001, after the completion of a two-year study, SCE had made the decision to replace its existing base of first generation DFRs. Presently, SCE is replacing anywhere from five to eight first generation DFR systems annually. Given the fact that SCE has DFRs in-service at over 60 of its major electrical substations, about ten years will be required to replace all of SCE's first generation DFRs.

This paper shares some of the considerations that led SCE to initiate a program to replace its first generation DFR systems. Some of the challenges that SCE's oscillographers faced in the past will be shared, and a few examples of the various features available with the newer technology DFRs will be shown. There will also be a discussion of how the newer technology DFRs have helped to reduce the oscillographer's time spent in the process of the retrieval of event records, so more time can be devoted to their analysis. The paper concludes with a short discussion of the various skill sets needed at SCE during the early part of the process to replace its first generation DFRs.

History of DFRs at Southern California Edison

Prior to the 1980's, the protection engineers at Southern California Edison (SCE) relied upon their installed base of magnetic drum, ink-type, and light beam recording systems to provide them with fault event data. The limited capability of these early fault recording systems frequently left the engineers without the data needed to verify proper operation of the more recently applied pilot relaying systems.

The arrival of the 1980's brought with it various computer-based technologies. One of these technologies was the development of computer-based fault recorder, more commonly known as the Digital Fault Recorder (DFR). Over the years a number of different manufacturers have offered various types of these first generation DFRs, each one having features of interest to the end-user. Fault records could now be remotely retrieved from the DFRs with the use of the high-speed 1200 baud modems of that day. The DFRs also offered the oscillographer a number of analysis tools formerly not available with the early fault recorders, such as displays of the fault current's sequence component quantities.

Beginning in 1985, SCE began a five year program to replace its early fault recording systems, primarily a large installed base of light-beam oscillographs, with the first generation DFRs. By 1990, SCE had first generation DFRs installed at 60 of its major electrical substations.

These first generation DFRs offered event record storage capabilities, something new to the oscillographers (in actuality, the Protection Engineering group) at SCE. These DFRs applied at SCE utilized static RAM, only, due to concerns that a Hard Disk Unit (HDU) may not perform reliably in SCE's service territory, where there is constant seismic activity.

Event records could also be retrieved from the remotely located DFRs with the use of high speed (typically 1200 baud) modem communications. This was a definite advantage, considering that in the past someone needed to go out to the station DFR, and physically remove the photographic paper (light-beam) from the oscillograph, and deliver the event recording to the analyst.

The first generation DFRs also provided something very familiar to SCE's oscillographers . . . a printed fault record very similar in format to that of the early fault recorders. This allowed a smooth transition from the early fault recorders to the first generation DFRs, since the printed formats were similar, just more data to be reviewed.

Advances in communication technology caused a movement away from the traditional modem-based communications to that offered by the use of high speed Ethernet. Over time, the PC workstations used by SCE's oscillographers were equipped with Ethernet capabilities, providing easy and quick access to various forms of information and data. Yet, their access to event recordings on the first generation DFRs continued to be through the use of the much slower speed modem-based technology, with the highest transfer rate available of 9600 baud. In addition, access to event records from these first generation DFRs were limited to the oscillographers, since the DFR's Master Station computer's proprietary software is the only path to the remote DFR's event recordings.

Requirements for the New Technology DFRs at SCE

As the search began for newer technology DFRs to apply at SCE, it soon became apparent that there was a need to open the access to the DFR event information to more than just SCE's Protection Engineering staff. The newer technology DFRs offer much simpler event viewing and analysis tools, which allow personnel with various levels of technical background the opportunity to extract information about a particular event that is of interest to them. For example, SCE's Grid Dispatch operations personnel can now view event records from the newer technology DFRs through Ethernet connections, providing timely data related to system and/or equipment outages.

Some of the elements of interest in the newer technology DFRs are shown below:

- Industry-recognized leader in development of highly reliable DFR systems
- "Open Access" to DFRs (no single Master Station required)
- Ethernet Communications to the DFRs
- Reliable high-speed modem communications to the DFRs
- Multiple Recording Speeds within the same DFR
- Continuous Channel recording capabilities
- Long-Term Storage of Event Data (other than Static RAM)
- Extensive, yet simple to use, DFR Master Station software
- Integrated database software for managing DFR records
- Capability to automatically export DFR event records into Comtrade format
- Capability to import Comtrade event records (from relays, DFRs, etc.)
- Sequence-of-Event record viewing capabilities
- Selectable event record initiation from all analog and digital input channels

Considering the advances in DFR technology, it seemed apparent that the time had come to evaluate the possibility of replacing SCE's first generation DFRs with those from the newer technology. The following items were major considerations in the process of identifying a need to replace SCE's first generation DFR systems with the newer technology DFRs.

1. DFRs considered as a necessity
2. Transformer failure events
3. Non-volatile storage of event data
4. Increase reliability of communications to DFRs
5. Record database capabilities
6. Open access to DFR Event Recordings
7. Ethernet communications to remote DFRs
8. Sequence of event capabilities

The process of evaluating the manufacturer's DFR technologies available today revealed that many of their systems have similar technical capabilities. Many are priced fairly close to one another, yet some of the manufacturers' DFRs were considerably more expensive than others. SCE's evaluation of the available new technology DFR systems revealed that the least expensive newer DFR systems did not necessarily meet the technology integration needs of SCE.

Thus, the search began to develop criteria to evaluate the type of new technology DFR that would best suit SCE. As a start, the requirements for the new technology DFRs needed to be identified. It became very clear from the start, though, that the driving force behind selecting a new technology DFR at SCE relied upon the immunity of the DFR system. In other words, the DFR system must record the proper event data under the harshest circumstances to be expected in a power system environment. In addition, due to the critical nature of the data recorded by the DFR system, the DFR technology must be hearty enough so that no event data is ever lost; at least before the analyst has the necessary time to review the event data. SCE's Management Team was very concerned with the first generation DFR's limited event recording and storage capabilities, where the failure of a major power system component, such as a power transformer unit, could result in the loss of data at the DFR.

1. DFRs Considered as a Necessity

Beginning in the 1990's, staffing levels were being reduced at many of the utilities within the U.S.A., leading to the loss of experienced personnel. During this time period, SCE lost a number of key personnel in various organizations. It soon became apparent that the same level of work, including the analysis of DFR records, would need to be completed by fewer personnel. Historically, the event records from DFRs provided the opportunity for the Protection Engineer to verify the proper application and/or operation of a particular relay or relay scheme.

As SCE's Management Team searched for tools to measure the performance of their electrical equipment, they soon discovered that a DFR had the capability of supplying data of interest to them. Examples of these data include fault clearing times, fault location, and magnitudes of current and voltage during system disturbances. Formerly, the DFR was considered a tool to be used by Protection Engineering, Test Technicians, and Operators. Now, the DFR had become a necessity to the Management Team to supply them with necessary system performance data in a timely manner.

Considering the heightened visibility of SCE's DFR systems, the DFRs ability to extract event records in a timely manner soon came under scrutiny. Historically, SCE's base of installed DFRs have experienced difficulties in transmitting their data to the DFR Master Station computers, primarily due to difficulties with the DFR's modem communication technology. A number of event records had been lost in the past, due to the DFR's static RAM memory filling to capacity, as a result of the DFR's communication lines being out-of-service for extended periods of time.

The difficulties in communication with the remote station DFRs were one of the drivers in the search for a new DFR technology. In light of the many internet and web-based software technologies available today, it was hoped that DFR data could be extracted through an Ethernet connection, with a high-speed modem line for backup communications.

Following are some of the situations and/or events that were considered during SCE's search for a new technology DFR system to meet its needs.

2. Transformer Failure Events

For those involved in the art and science of protective relaying, it is rare that electrical system failures result in such extensive damage that even the station's fault recording equipment fails to capture the event data. Yet, this is what nearly occurred at two of SCE's major 500/220kV electrical substations. In each case, a large 500/220kV power transformer unit failed in-service, resulting in the operation of the respective transformer's sudden pressure and transformer differential protection. Yet, each station's power transformer failed catastrophically, resulting in an oil fire at each substation. In both cases, the oil fire caused significant damage to a number of each station's control cables.

Both station's first generation DFRs had limited memory to capture all of the events that occurred as a result of these major power transformer failures, and eventually lost some of the event data that occurred just a few seconds after the start of the event. In addition to the DFRs limited static memory, there were no provisions for backup event storage, such as a hard disk drive, or use of a UPS power supply to the DFRs DC power supply. In both cases, the station's DC system, which supplies the DFRs power supply, experienced an outage during the event, which also resulted in loss of event data at the DFR.

Recently, in March of 2003, SCE experienced another failure of a large 500/220kV power transformer unit, this time at a different substation. Similar to the past other two power transformer failures, this transformer's sudden pressure and differential protection operated properly. Once again, the power transformer failed catastrophically, resulting in an oil fire, eventually causing severe damage to the station's control cables. In this case, many of the station's control cables were damaged by the ensuing oil fire within the station, eventually resulting in an outage of the station's DC system.

Unlike the other two substations, this substation had a newer technology DFR installed at the time of this power transformer failure. The new technology DFR's HDU stored all of the event data, including the initial fault on the power transformer unit, up until the time when the substation lost its entire DC system. The loss of the station's DC system resulted in the DFR losing all of its recording's stored in static RAM, but all of the events remained stored on the DFR's HDU. Once the station's DC system was restored a day, or so, later, the event recordings were retrieved from the DFR's HDU, providing the engineers the data needed to analyze the faulted power transformer. SCE's Management Team was very pleased to know that their investment in the newer technology DFR at this substation ultimately resulted in no lost event data for this particular power transformer failure.

3. Non-Volatile Storage of Event Data

On August 10, 1996, a significant event occurred on the Western power grid, eventually resulting in the "islanding" of various parts of the grid. In the hours following this major event it became apparent that many of the DFRs at SCE had captured only portions of the event, in part due to their event storage limitations at the time. The DFRs applied at SCE up to that time used only static RAM, which could record only seconds of data, and this particular event lasted for well over a minute. The length of this event caused the static RAM to become filled on many of SCE's DFRs, well before the event's conclusion, so much of the event data was lost.

The newer technology DFRs offered SCE high capacity storage of event data in the form of a Hard Disk Unit (HDU), with event storage capacities available today in the gigabytes. In actuality, the HDU serves to minimize the possibility of losing event information. This is primarily due to the fact that during a system event the data recordings are immediately transferred from the DFR's static memory (RAM) to the HDU. The availability of the DFR's HDU allows nearly immediate storage of event data, relieving the DFR's static RAM to continue the process of capturing real-time event data. In the past, SCE's first generation DFRs had limited capacities of static RAM and no HDUs, many times resulting lost event recordings. If communications to the remote DFR is lost for any reason, the newer technology DFRs continue to store event data on its HDU. Once communications to the remote DFR have been re-established, the event recordings are available for access from the DFRs HDU.

SCE's service territory recently experienced a series of severe windstorms, which caused a number of outages throughout various parts of its subtransmission (66kV) systems, primarily due to downed power poles and their related line conductors. SCE's communication facilities also experienced a number of outages during the severe winds, which resulted in long-term outages of the modem communication circuits to some of its DFR systems. One DFR had its remote communication circuits interrupted for nearly five days. Yet, this DFR had recently been upgraded to the newer DFR technology it had built-in HDU record storage capability, so no event data was lost.

4. <u>Increase Reliability of Communications to DFRs</u>

As a part of their normal operation, SCE's first generation DFR systems experienced a number of communication-related problems. In many cases, it became very difficult to identify the source of the problems, since the communication systems did not inform the DFR at the time of its failure. In the application of the newer technology DFRs at SCE, it was noted that they provided a logging feature, which displays information related to operation of the various parts of the DFR system. This logging feature has been a very helpful tool in identifying various issues in the operation of the DFR system, from the communication system to the DFRs hardware performance. Figure 1 shows an example of this operations log, and this display shows that this particular DFR had received some warning and/or informational messages during its startup testing. It can be seen that this log not only displays the DFRs hardware that was having problems, but also displays the time of the problem. This type of information has proven to save time in the determination of problems experienced with the DFR and its related external systems.

Figure 1 shows the operation log from SCE's new technology DFR installed at its Antelope Substation. This operations log shows various informational, warning, and error messages available for viewing by the analyst. This logging capability has proven to be very handy in determining the date and time that a particular part of the DFR systems had experienced failures, especially as a result of remote DFR communication failures. More often, though, this logging screen has been used to determine when the DFR's configuration parameters were revised, and by which user (based on the user's password shown within an entry in the operations log).

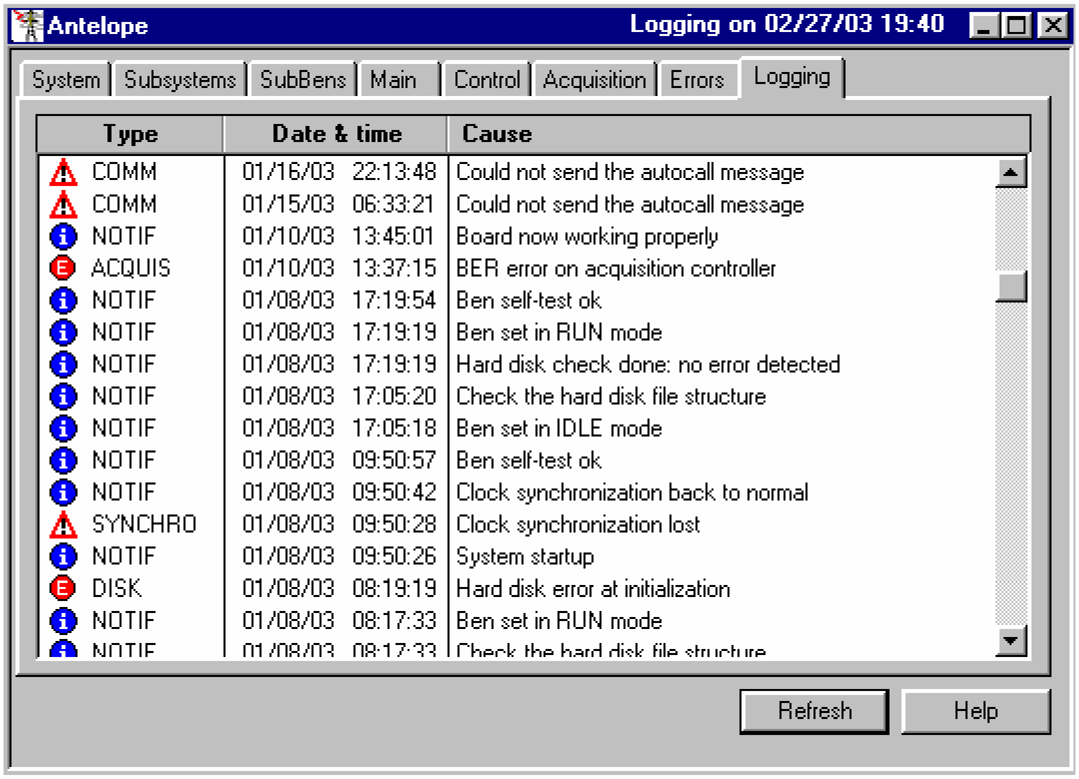


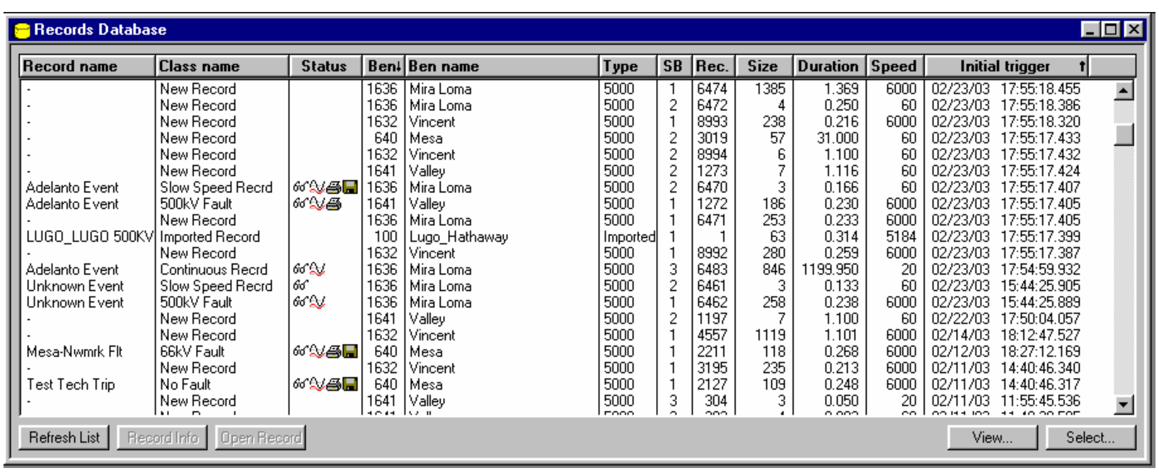
Figure 1
Example of DFR's "Operation's Log"

5. Record Database Capabilities

For many years, SCE had stored its event records on floppy disk media. Yet, when attempts were made to retrieve the information, it soon became apparent that the stored database parameters were not compatible with those of the current database. Thus, many older DFR records could not be accessed with the latest DFR software.

In looking at newer technology DFR systems available today, many of them offer database search engines as built-in features of their proprietary Master Station software. These database search engines can be time savers, when the oscillographer is searching for an event record, or a group of event records, that are of particular interest. In many cases, event records from the past are searched based on the time of their occurrence. In reviewing the performance of a particular type of protective relay, the availability of a database search engine can aid in grouping event records from different dates and/or times that show the performance of a particular relaying system.

Figure 2 shows a typical records database feature of the new technology DFRs used at SCE. One of the most valuable features of this type of database is the ability to quickly search for event files of interest. Event files can be given customized "record name" and "class names," which provide the oscillographer a more flexible method of searching for an event, or groups of events, of interest. Thus, they are not limited solely to the event file's trigger date and/or time during their search through the database. This feature has proven to be a real time saver for the oscillographers (Protection Engineers) at SCE, since they spend less time locating the events of interest, and more time in the analysis of the events of interest.



Record name	Class name	Status	Ben	Ben name	Type	SB	Rec.	Size	Duration	Speed	Initial trigger
-	New Record		1636	Mira Loma	5000	1	6474	1385	1.369	6000	02/23/03 17:55:18.455
-	New Record		1636	Mira Loma	5000	2	6472	4	0.250	60	02/23/03 17:55:18.386
-	New Record		1632	Vincent	5000	1	8993	238	0.216	6000	02/23/03 17:55:18.320
-	New Record		640	Mesa	5000	2	3019	57	31.000	60	02/23/03 17:55:17.433
-	New Record		1632	Vincent	5000	2	8994	6	1.100	60	02/23/03 17:55:17.432
-	New Record		1641	Valley	5000	2	1273	7	1.116	60	02/23/03 17:55:17.424
Adelanto Event	Slow Speed Recrd		1636	Mira Loma	5000	2	6470	3	0.166	60	02/23/03 17:55:17.407
Adelanto Event	500kV Fault		1641	Valley	5000	1	1272	186	0.230	6000	02/23/03 17:55:17.405
-	New Record		1636	Mira Loma	5000	1	6471	253	0.233	6000	02/23/03 17:55:17.405
LUGO_LUGO 500KV	Imported Record		100	Lugo_Hathaway	Imported	1	1	63	0.314	5184	02/23/03 17:55:17.399
-	New Record		1632	Vincent	5000	1	8992	280	0.259	6000	02/23/03 17:55:17.387
Adelanto Event	Continuous Recrd		1636	Mira Loma	5000	3	6483	846	1199.950	20	02/23/03 17:54:59.932
Unknown Event	Slow Speed Recrd		1636	Mira Loma	5000	2	6461	3	0.133	60	02/23/03 15:44:25.905
Unknown Event	500kV Fault		1636	Mira Loma	5000	1	6462	258	0.238	6000	02/23/03 15:44:25.889
-	New Record		1641	Valley	5000	2	1197	7	1.100	60	02/22/03 17:50:04.057
-	New Record		1632	Vincent	5000	1	4557	1119	1.101	6000	02/14/03 18:12:47.527
Mesa-Nwmrk Flt	66kV Fault		640	Mesa	5000	1	2211	118	0.268	6000	02/12/03 18:27:12.169
-	New Record		1632	Vincent	5000	1	3195	235	0.213	6000	02/11/03 14:40:46.340
Test Tech Trip	No Fault		640	Mesa	5000	1	2127	109	0.248	6000	02/11/03 14:40:46.317
-	New Record		1641	Valley	5000	3	304	3	0.050	20	02/11/03 11:55:45.536

Figure 2
Example of "Records Database"

6. Open Access to DFR Event Recordings

In the past, SCE's DFR event records have typically been available to only a limited number of Master Stations and/or users, primarily its Protection Engineering staff. Thus, the analysis of event records was limited to a very specialized group of people, focused primarily on the performance of protective relaying systems. In addition, if electrical system phenomena (such as circuit breaker re-strikes, re-ignitions, etc.) were captured on the event record, the personnel reviewing the event record may overlook such phenomena, since their focus was on the performance of protective relaying systems.

The newer DFR technology has opened the DFRs event records to a number of different organizations within SCE. Today, event records from SCE's newer DFRs can be viewed not only by its Protection Engineering staff, but now can be viewed by its Operations, Apparatus (staff responsible for the application of circuit breakers, disconnects, transformers, etc.), and Test Technician staff. Thus, more data is available to the people making the decisions in the removal or restoration of electrical equipment to service.

7. Ethernet Communications to Remote DFRs

SCE's search for a newer technology DFR was guided by the need for Master Station DFR software that was powerful, yet simple to use. In addition, the time spent performing various tasks with the DFR, such as channel groupings, sensor (or trigger) configurations, etc. needed to be kept to a minimum. Ultimately, in an effort to minimize this time element, SCE's Protection staff worked closely with its Information Technology staff to develop an Ethernet connection to each of its newer technology DFRs. The availability of the Ethernet in the newer technology DFRs is the single most vital feature responsible for SCE spending less time with its DFRs. From revising a particular DFR's configuration to retrieving an event record of interest, the Ethernet has provided SCE with the ability to perform the desired tasks in much less time than what could be accomplished with just the availability of modem technology.

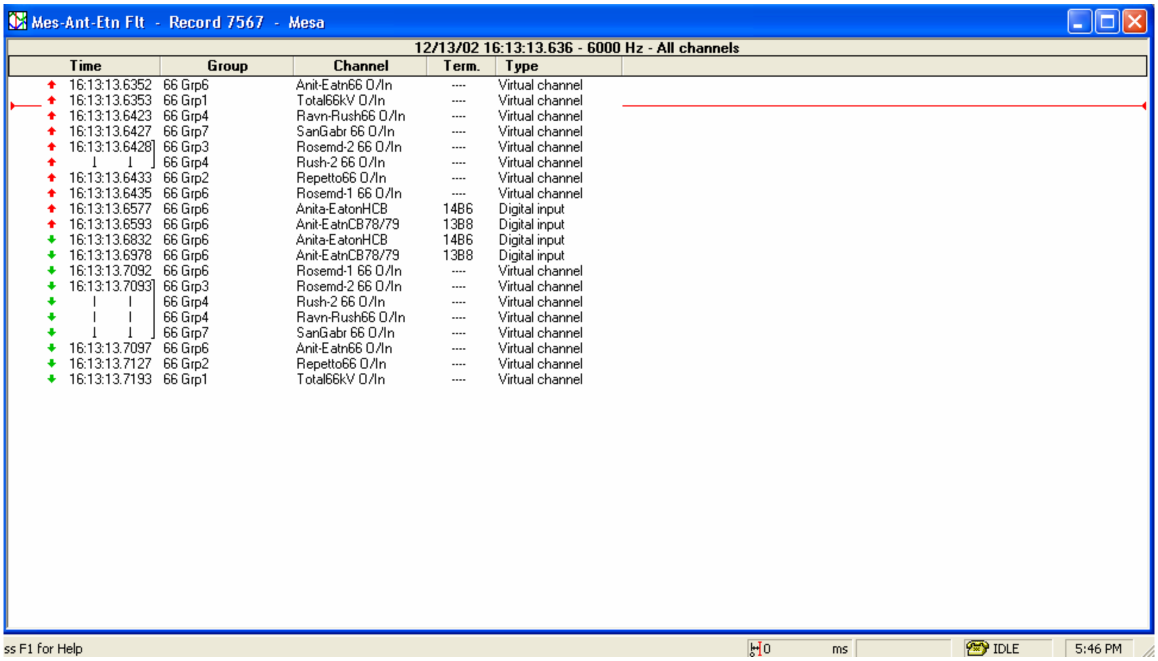
8. Sequence of Event Capabilities

Following the power system disturbance event of August 10, 1996, it became apparent that there was a need to report the Sequence Of Events (SOE) as quickly as possible. Following this event, SCEs Protection Engineers were requested to provide SOE data as quickly as possible. Unfortunately, the SOE data needed to be extracted from "paper" DFR recordings, so the task of extracting event times became painstaking and tedious. Ultimately, the compilation of the event-related SOE data required weeks to develop.

The newer technology DFRs include SOE capabilities as a part of their standard system. If a major power system event were to occur today, such as that of August 10, 1996, the newer technology DFRs provide quick and easy access to the event's SOE data, which can easily be appended to various types of reports.

An example of the new technology DFRs' SOE event view is shown in Figure 3. This type of SOE view shows the particular time that each DFR channel experienced a change-of-state (either from open to closed, or from closed to open). On the left of each time signature is an arrow which points either upward or downward. The upward pointing arrow signifies a change-of-state for a particular DFR channel, and the downward pointing arrow signifies that the DFR channel has returned to normal.

The SOE data shown in Figure 3 is an actual display of the events that occurred during a fault on one of SCE's 66kV substransmission lines, specifically the Mesa-Anita-Eaton 66kV line. From the SOE view shown in Figure 3, the analyst can easily determine the time periods between operations of the channels of interest. Thus, the SOE data ca be used to validate proper performance of relaying systems, circuit breakers, and their related control schemes.



Mes-Ant-Etn Flt - Record 7567 - Mesa

12/13/02 16:13:13.636 - 6000 Hz - All channels

	Time	Group	Channel	Term.	Type
↑	16:13:13.6352	66 Grp6	Anit-Eatn66 O/In	----	Virtual channel
↑	16:13:13.6353	66 Grp1	Total66kV O/In	----	Virtual channel
↑	16:13:13.6423	66 Grp4	Ravn-Rush66 O/In	----	Virtual channel
↑	16:13:13.6427	66 Grp7	SanGabr 66 O/In	----	Virtual channel
↑	16:13:13.6428	66 Grp3	Rosemd-2 66 O/In	----	Virtual channel
↑		66 Grp4	Rush-2 66 O/In	----	Virtual channel
↑	16:13:13.6433	66 Grp2	Repetto66 O/In	----	Virtual channel
↑	16:13:13.6435	66 Grp6	Rosemd-1 66 O/In	----	Virtual channel
↑	16:13:13.6577	66 Grp6	Anita-EatonHCB	14B6	Digital input
↑	16:13:13.6593	66 Grp6	Anit-EatnCB78/79	13B8	Digital input
↓	16:13:13.6832	66 Grp6	Anita-EatonHCB	14B6	Digital input
↓	16:13:13.6978	66 Grp6	Anit-EatnCB78/79	13B8	Digital input
↓	16:13:13.7092	66 Grp6	Rosemd-1 66 O/In	----	Virtual channel
↓	16:13:13.7093	66 Grp3	Rosemd-2 66 O/In	----	Virtual channel
↓		66 Grp4	Rush-2 66 O/In	----	Virtual channel
↓		66 Grp4	Ravn-Rush66 O/In	----	Virtual channel
↓		66 Grp7	SanGabr 66 O/In	----	Virtual channel
↓	16:13:13.7097	66 Grp6	Anit-Eatn66 O/In	----	Virtual channel
↓	16:13:13.7127	66 Grp2	Repetto66 O/In	----	Virtual channel
↓	16:13:13.7193	66 Grp1	Total66kV O/In	----	Virtual channel

ss F1 for Help 0 ms IDLE 5:46 PM

Figure 3
Sequence of Event (SOE) View

Sample Event Recordings from SCE's New Technology DFRs

1. Use of Transient Recording Speed

On its new technology DFRs, SCE applies a 6000 Hz sampling rate in its high-speed event recordings, referred to as "transient" recording.

An example of the type of data that can be extracted from a "transient" recording is shown below, in Figure 4. This "screen capture" displays a recording of a double-line-to-ground fault that occurred on one of SCE's subtransmission systems (please forgive the year shown of the recording, 1970, since there was a problem with the GPS receiver supplying the IRIG-B signal to the DFR at the time of the recording . . . the actual year was 2002).

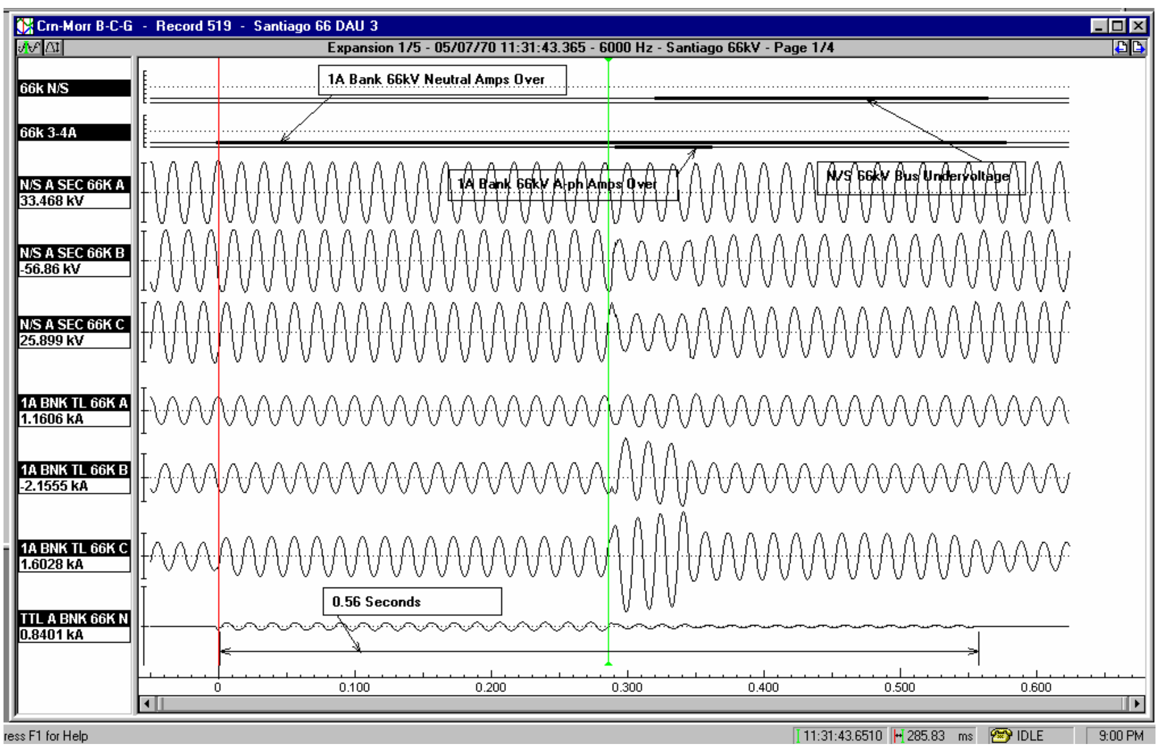


Figure 4
"Transient" Recording
Sampling Rate = 6000 Hz

2. Use of Slow-Speed Recording

SCE is applying a second slow speed recording on their new technology DFR systems, where selected analog input channels are recorded at a 60 Hz sampling rate. These slow speed recordings typically last for about 10 seconds, and are initiated by a deviation in one of the DFRs starting sensors (typically undervoltage or overcurrent).

An example of the type of data that can be extracted from a slow speed recording is shown below, in Figure 5. This screen capture displays a recording of system frequency, line Amperes, and bus voltage quantities at SCE's Valley 500kV Substation, during a recent WECC system event.

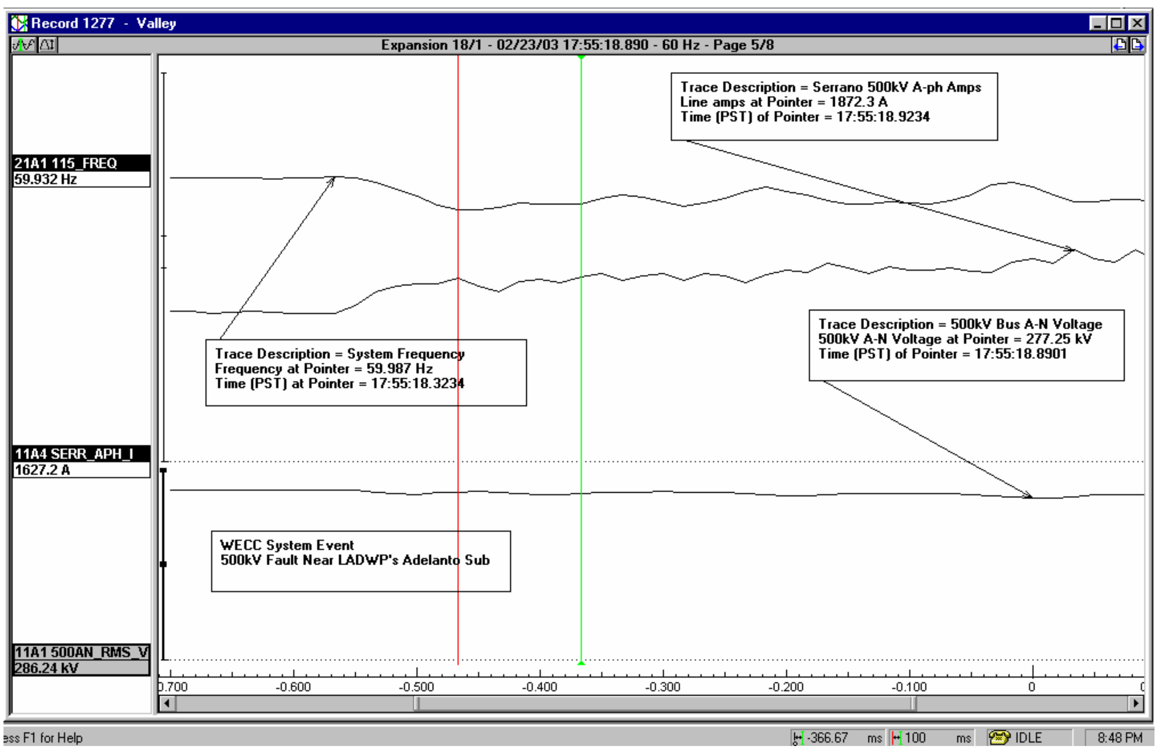


Figure 5
Slow Speed Recording
Sampling Rate = 60 Hz

3. Use of Continuous Recording Speed

SCE is applying a third continuous recording speed on its new technology DFR systems, where selected analog input channels are recorded on a continuous basis, at a 20 Hz sampling rate. These continuous recordings last for 20 minutes, so that a new continuous recording is started every 20 minutes. At this point in time, most of the newer technology DFRs have enough Hard Disk Unit (HDU) storage to allow up to three (3) months of "continuous" records to be stored, before the DFR's HDU is filled to capacity and begins to write over the older event files.

An example of the type of data that can be extracted from a continuous recording is shown below, in Figure 6. This screen capture displays a recording of the WECC's 500kV system frequency during a recent 500kV system disturbance on the WECC grid, which resulted in a drop in the system frequency from 59.98 Hz to 59.794 Hz over a period of about 9 seconds.

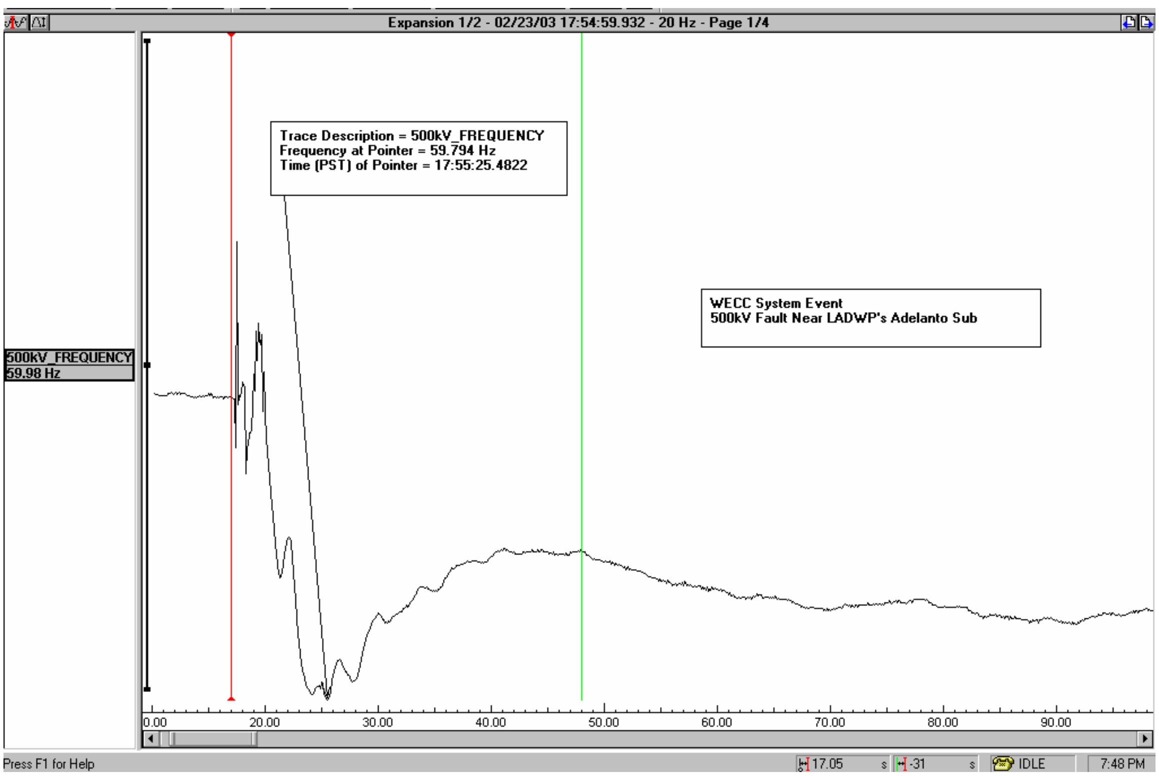


Figure 6
Continuous Recording
Sampling Rate = 20 Hz

4. Use of Calculated Channel

Figure 7 displays the voltage and current quantities for a fault that occurred on one of SCE's 66kV substransmission lines. Referring to Figure 7, the fault started out as B-ground, and after about 34 cycles develops into a B-to-C-ground fault. Unfortunately, the event recording stops before the fault is cleared, shown by the fact that both the B-phase and C-phase line currents remained at elevated levels at the end of the event record. When reviewing the setpoints on the DFRs sensors (or triggers), it was found that this DFR only triggered an event record when the bus's phase voltage level dropped below 90% of nominal, or when the line's residual (shown in Figure 7 as 3I0) current rose above the level of 150 amperes. Near the end of the record, it can be seen that both the voltage on the bus and line's residual current trigger quantities were not of sufficient levels to maintain a trigger state of the DFR. Thus, the DFR recording ended after a pre-programmed post-time interval.

The new technology DFR offers the opportunity to extract the data from a particular channel, or a group of channels, and perform a mathematical calculation and the ability to display the newly calculated quantity in the DFR's event recording. In addition, these calculated channels can also be used to trigger event recordings at the DFR.

For example, referring once again to Figure 7, the station's bus voltages (only a single voltage quantity is shown in Figure 7) were used to create a calculated channel of the negative sequence voltage quantity at the bus. Prior to the fault, the negative sequence voltage level at the bus was about 0.4 kV. During the fault, the negative sequence voltage rose to about 1.3 kV, followed by a rise to about 5.6 kV, and dropped back down to about 3.2 kV at the end of the fault record.

Thus, had the negative sequence quantity of the bus voltage been used to trigger an event record at the DFR, at a level somewhat below 3.2 kV, the event recording shown in Figure 7 would most likely have continued until the fault actually cleared from the system. In fact, as a result of this analysis since the time of the fault on this SCE line the bus voltage's negative sequence quantity has now been configured to trigger an event recording at the DFR, should the negative sequence voltage level rise above 1.5 kV.

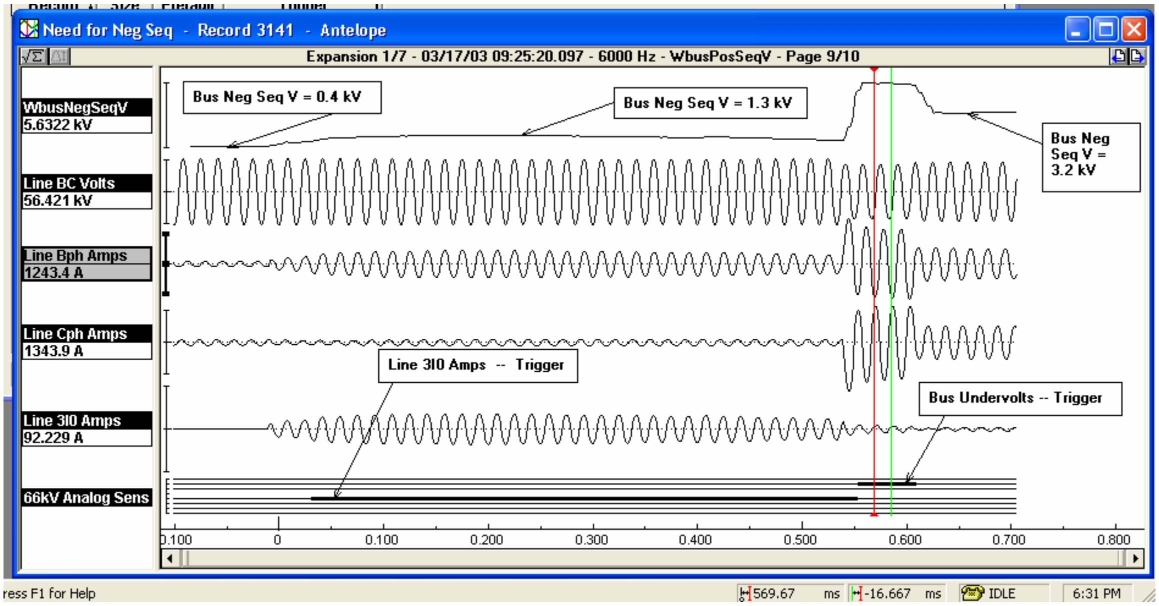


Figure 7
Negative Sequence Overvoltage Event Triggering

Staffing Considerations in Replacing DFR Systems

SCEs application of the newer DFR technology has revealed that the proper application of the DFRs has required more of SCE's time than first expected. Unfortunately, DFR systems cannot install themselves, so the process of successfully implementing the newer technology DFRs requires a team effort.

As the process began to replace and/or retro-fit the first generation DFRs with those from the newer technology, it became apparent that a number of the following issues would need to be addressed as a part of this process: number of issues arose during the early part of the process, revealing that the following questions would need to be addressed:

1. Should the DFR's existing channel count be expanded? (analogs and/or digitals)

2. Should the new technology DFR replace the first generation DFR system's Acquisition Units on a channel-by-channel basis, or will new analog and digital channels be added to the existing DFR system?

3. Which power system quantities are desired, in the process of initiating a DFR recording? (undervoltage, overcurrent, negative sequence, zero sequence, power swings, etc.)

4. What are the acceptable levels that each power system quantity initiates a DFR recording (i.e. % voltage dip, current magnitude, negative sequence overvoltage, etc.)?

5. What is the maximum time that each initiating quantity (analog and/or digital channels) will be allowed to trigger a DFR recording?

6. What is the acceptable practice of revisions to the DFR station's drawings, so that it now becomes evident that the new technology DFR has replaced the first generation DFR?

7. Who will coordinate the entire process of making sure that these new technology DFR systems are installed in a fairly consistent manner?

Expanding a bit on the last question from above, SCE put together a team to address the various aspects related to the replacement of its older DFR systems. SCE's major team players, and some of their critical activities related to the application of the newer technology DFRs, are shown below:

Senior Lead Protection Engineer --

1. DFR project sponsor;
2. Develops prioritization of sites to have their respective DFRs upgraded;
3. Develops order requirements for each of the DFR upgrade systems to be installed;
4. Coordinates the scheduling of the on-site commissioning/training for each of the DFRs;
5. Develops the DFR point-listing of analog, digital, and sensor channel requirements;
6. Develops configuration file programming for each of the newer technology DFRs;
7. Provide on-site commissioning/training for DFRs alongside the DFR manufacturer's representative, or in some cases alone, when the DFR manufacturer's representative is unavailable.

Senior Area Protection Engineer --

1. Develops the first elementary (sometimes referred to as "schematic") and wiring (sometimes referred to as "connection") drawings for the application of the newer technology DFRs to one of SCE's stations;
2. Coordinates the efforts to have this "first design" implemented as a "standard" for all future DFR installations from this particular DFR manufacturer.

Senior Information Technology (IT) Engineer --

1. Provider of all outside communications technology to the newer technology DFR;
2. Coordinates IT team to review all DFR sites for their capability to support the installation of Ethernet communications to the DFRs, and to develop a strategy to upgrade existing communications infrastructures, at proposed DFR upgrade sites.

Senior Technical Specialist --

1. Provides technical support to the Test Technician staff responsible to install the newer technology DFR at each site;
2. Support the application of the DFR configuration file programming and in the input channel calibration and testing of the DFRs.

Senior Design Engineer --

1. Project Engineer responsible for the design implementation of the newer technology DFRs at each of the identified sites;
2. Identify the needs of all parties involved in the application of the newer technology DFRs at each site, and develop the appropriate design specification;
3. Coordinate the ordering and arrival of all equipment related to the application of the newer technology DFRs at each site.

The above shows that SCE had a number of different individuals involved in the process of replacing its first generation DFRs. Each of these people brought a different skill set to the DFR replacement process. Having various people involved in the process turned out to be a great advantage, since each individual brought a different perspective to the project. In addition, each of them had a share in standardizing the process of applying the newer technology DFRs at SCE. The outcome of this team approach throughout the DFR project resulted in a final product applied consistently throughout the company.

Summary

SCE's search for a new technology DFR system has been both challenging and exciting. It has been a stretch learning experience for all that have been involved with the project. The most noticeable difference in the typical day of one of SCE's oscillographers (Protection Engineers) is that they have more time to work on new relay applications and their related settings, since they are spending less time and effort in the retrieval and analysis of power system event records from their new technology DFRs.

SCE's use of the newer technology DFR's Ethernet communications capabilities have provided more reliable access to the remotely located DFRs, and has opened access to event recordings to people working in the Operating and Apparatus Engineering (circuit breakers, transformers, etc.) groups. From a data storage perspective, SCE has taken advantage of the newer technology DFR's Hard Disk Unit, significantly decreasing the possibility of losing event data at the remote DFR, which is critically important in the application of a fault recording system.

Biographical Information

Robert Baldwin received his B.S.E.E. from the Long Beach campus of the California State University in 1982. After spending a short time as a Customer Engineer with Hewlett Packard, he hired on with the Southern California Edison Company in 1984. During the early part of his career at Edison he spent five years in the "crafts," holding the positions of Substation Electrician and Test Technician, followed by one year as a Shop Engineer in Edison's Large Apparatus Repair facility. He transferred to the Protection Engineering group in 1990, where he is presently one of the group's Senior Engineers, with the primary responsibility for the application and implementation of Digital Fault Recording systems at Edison. Robert was former lecturer in the Power Systems portion of the Professional Engineering Review course in the field of Electrical Engineering at California State University, Long Beach. He is a registered professional engineer in the state of California.

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