RFHAWKEYE

The Solution for RF Transmission System Monitoring

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1 Introduction – Why Monitoring is Needed

As any broadcast operator knows, the major RF components outside the transmitter building – the transmission line and the antenna – are not only critical and essential in the signal transmission chain, they are also very expensive to acquire, to install and, most importantly, to repair, typically requiring skilled riggers and specialized equipment. Even though these RF components are robustly designed for unattended operation in all environments, problems can occur. Consider that a failure in the line or antenna can interrupt the broadcast service to millions of end users until the problem can be identified, located and repaired – all at significant cost to the broadcaster. It is then, perhaps, somewhat surprising that the monitoring of the condition of the line and antenna has generally been left to a reflected power or VSWR circuit in the broadcast transmitter. Such protection does protect the transmitter, but it has been unable to prevent many examples of spectacular failures of line and/or antenna components, resulting in catastrophic damage and significant off-air time. It is clear therefore that the broadcast industry is long overdue for an effective and reliable monitoring system that can identify potentially damaging anomalies early, thus minimizing downtime and protecting the operator's investment by preventing catastrophic damage.

2 What Monitoring is Available and its Pros and Cons

As noted above, for many years the only monitoring, and therefore protection, of the RF line and antenna was provided in the transmitter by way of directional couplers and observation of reflected power (typically, although some transmitters do calculate system VSWR, providing better monitoring). The alarm levels were generally set to protect the amplifying devices in the transmitter and allowed wide variations in reflected power with no logical indication of degradation of individual RF components. Further, these methods can only measure the resultant reflected power or VSWR of the entire system at the coupler position, providing no indication of the presence of the multiple reflections along the line, caused by insulators, transformers, elbows, gas barriers and so on, as well as by the antenna. In many cases, by the time the transmitter protection activates, the damage has already occurred with no information provided on the location of the fault or the extent of the damage – not much help for the troubleshooting phase! In some cases the damage is occurring and the protection does not even activate. Regardless, that troubleshooting requires a skilled RF engineer, using a network analyzer, working in parallel with skilled riggers to even identify the source of the problem before corrective action can be defined and then deployed. Even if the observant transmitter engineer has noted some anomalous VSWR behavior before the transmitter faults, the RF engineer still has to shut-down the transmitter and break apart the line at a suitable point before looking to identify the source of the anomaly – which may disappear as the system cools.

More sophisticated systems, deployed recently, install VSWR sensors in multiple locations in the transmission system, including at the antenna input and the base of the vertical line run, thus introducing the possibility to localize the faults by correlating measurements taken at different points in the system. Note that these systems are in addition to, and independent of, the transmitter monitoring, although some level of integration is generally possible.

A different approach - a system with the capability of detecting and even localizing arcs in the line– has also appeared in the market recently. Although information of the occurrence and position of arcs is definitely valuable in troubleshooting, this information is provided after the degradation has deteriorated to the point of voltage breakdown. Damage to components will likely already have occurred requiring emergency action. Such a system may, however, limit the extent of the damage to the RF system if the operator reacts accordingly.

In general, all the mentioned systems share a common limitation: they are reactive i.e. a significant degradation has already occurred before the monitoring system provides an indication of the problem. Systems relying on arc detection will likely miss the small degradations in components or connections that have to occur before an arc develops. In other words, the arc is not an early indication of a deteriorating issue, but just the evidence of an issue that has been deteriorating over some time to the point of voltage breakdown.

3 Why RFHAWKEYE?

There is a better solution – real-time monitoring of all components of the line and antenna system that can localize small changes in VSWR. RFHAWKEYE (RFH) is such a system. By monitoring the line in real-time TDR-like mode, it can detect and locate local changes in VSWR or Return Loss (RL) with a sensitivity far surpassing that of overall system VSWR detectors, also identifying when and where a potentially catastrophic arc has occurred. With 8 inch accuracy and 2 foot resolution, RFH can monitor the detailed behavior of the system, identifying each single connector or elbow in the line, and identifying changes as low as 1.004:1, much earlier than would be visible in the overall VSWR. Thresholds can be set to generate warnings and alarms if the VSWR at a particular location (or locations) varies beyond acceptable limits. The operator or monitoring service can then determine if corrective action should be taken immediately, before the situation deteriorates, or whether inspection can be scheduled later.

Analysis of multiple transmission line failures, in which evidence of catastrophic voltage breakdown (arcing) was found, indicates that the arcing was not the initial failure – the arcing occurs as result of deterioration of other components through a variety of mechanisms – all of which will show up as a deterioration in VSWR before the catastrophic arcing occurs. Since, in the majority of instances, the transmitter itself is not damaged, this confirms that most, if not all, current protection systems protect the transmitter - not the transmission line and other RF components i.e. the transmitter protection may well “see” the catastrophic arcing and shut down with no indication to the operator of what actually occurred. RFH has been developed to provide operators with advance warning of the development of problems in transmission line and antenna components, such that catastrophic voltage breakdown and damage does not occur. However, since the rate and magnitude of degradation will likely be different in each case, depending on the nature of the degradation, the power level, the environment and so on, it is conceivable that a rapidly deteriorating event can occur and an operator cannot intervene on time. RFH can also identify the characteristic signature of an actual arc and display the location of that arc. As will be shown later, an arc was simulated by introducing a probe into a section of transmission line causing an increase in VSWR at the probe location well before the voltage breakdown of the arc occurs. RFH will capture and display both the degradation leading to the arc and the characteristic signature of the arc.

Executing a continuous in-service TDR-like measurement not only enables the early detection, but also determines the exact position, of anomalies thus providing valuable, time-saving information for the rigging crew to confirm and perform necessary repairs.

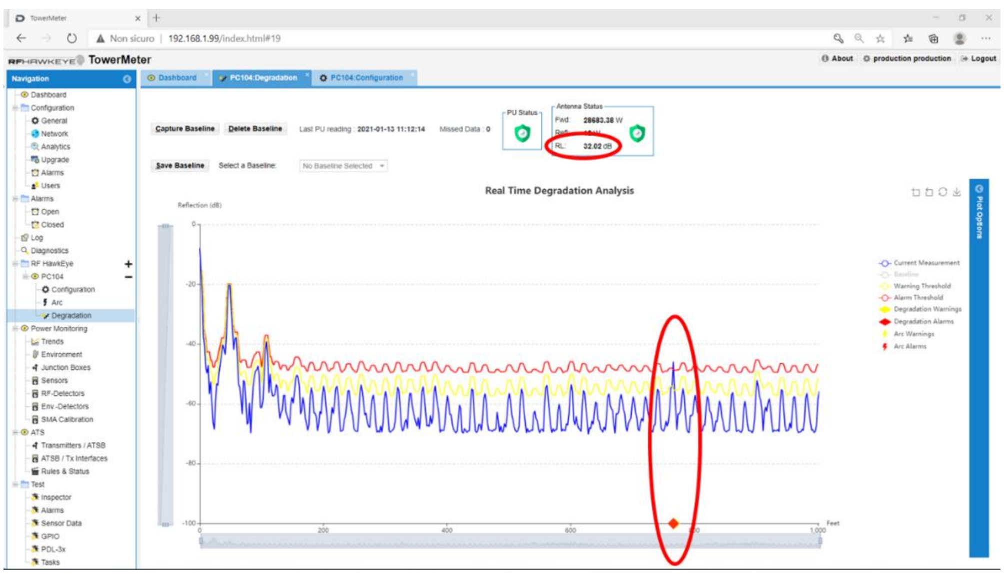
The RFH system uses Internet Protocol (IP) and can be readily integrated into the operator’s network, or that of a remote monitoring service, allowing the view of system status and sending timely notifications of detrimental system condition to all the relevant key people. Forward and Reflected power monitoring at the RFH coupler is integrated within RFHAWKEYE, providing rapid indication of whether the anomaly is in the antenna or the transmission line.

RFHAWKEYE is independent of the transmission system used, works with ATSC 1.0, ATSC 3.0, FM, DVBT-xx, and others.

4 Examples

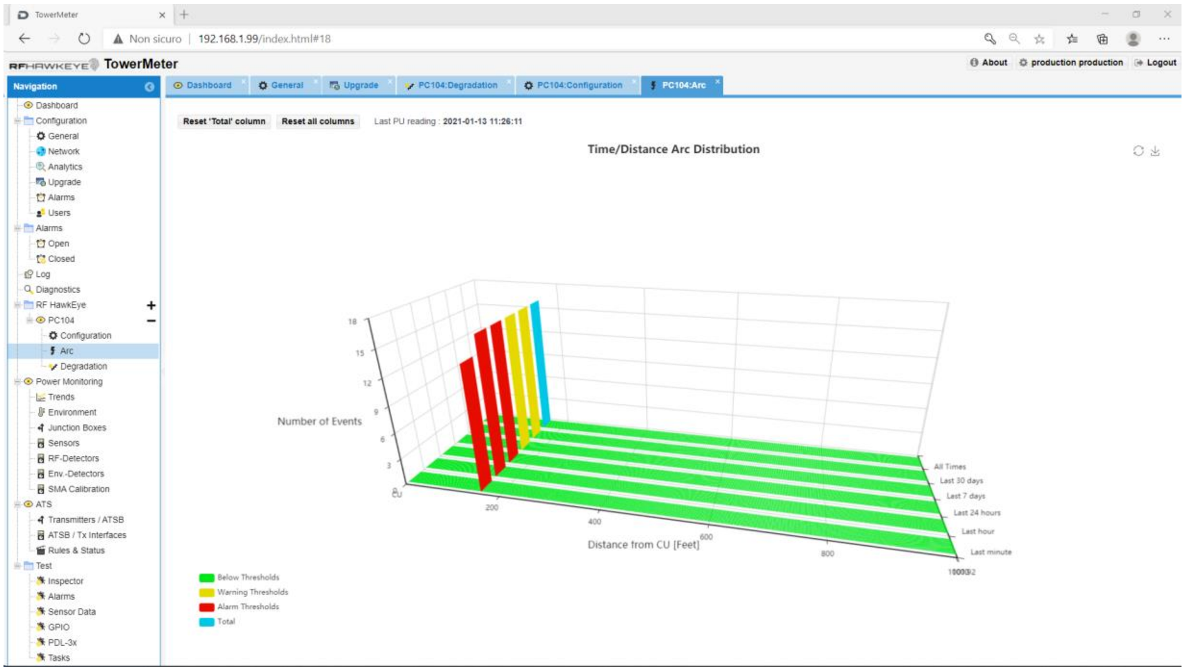
4.1 Typical Case of Degradation

Consider a fully installed system with the reflection measured by a detector at the input of the transmission line reading overall Return Loss (RL) = -33dB (or VSWR of 1.046:1). This is very good. But this system value of 33dB is the result of the combination of multiple reflections from transmission line components such as Teflon insulators, flanges, elbows, transformers and gas-barriers, and each of them could be around -50dB (1.006:1). Now suppose that, for some reason, one of the Teflon insulators or bullets undergoes a minor degradation at, say, 760ft. Its RL jumps from -50 to -45 dB (1.011:1). This will have virtually no impact on the broadcast system operation - it is not a major change in overall VSWR measurement. The station will still be working perfectly and the detector value at the input will go to maybe -32.2dB (1.05:1), a 1.004:1 change. The change would most likely go unnoticed – the resolution of most VSWR or RL monitoring in use today simply won't show the change. However, RFHAWKEYE will show the magnitude and location of this change. Perhaps the change is cyclical and of no concern or perhaps the change is the first indication of the degradation of an insulator or bullet – which will only get worse. With RFHAWKEYE, the operator has been warned: "There is a change from 1.006:1 to 1.011:1 at 760ft". This change, along with any others, can now be tracked and, if it gets worse, corrective action can be initiated before a failure occurs.



4.2 Faulty Installation

Now consider that, during installation of a transmission line, one or more Teflon insulators is accidentally contaminated. The contamination is minor and the normal system tests before operation do not raise a warning flag. Then RF power is applied and the contamination starts heating up, potentially burning the surface of the Teflon insulator leaving carbon residue, initiating a downward spiral of damage starting at the insulator but progressing back towards the transmitter. RFHAWKEYE would "see" the small changes of the VSWR at the Teflon insulator and would send out a warning and eventually an alarm before the Teflon insulator is fully deteriorated or arcing has occurred. As mentioned in example 1, the transmitter monitoring or any other available monitoring system would most likely not react at the onset of the issue, potentially resulting in catastrophic and extensive damage to the line.

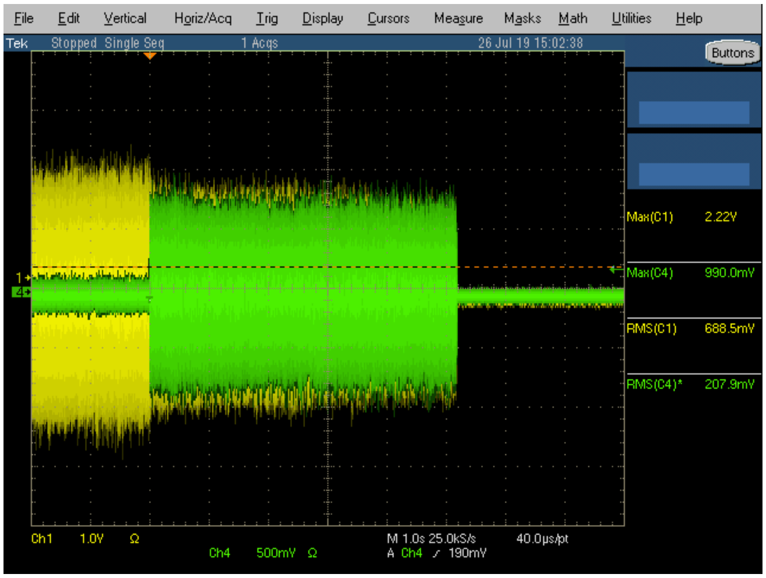


4.3 Arc Simulation

As noted above, arcing is the end result of a degradation process that generally results in catastrophic damage to transmission line and RF components. Degradation of local VSWR always occurs before the actual voltage breakdown. This is true whether the degradation is initiated by a poor contact in the inner conductor connections or contamination of insulators between inner and outer conductor. RFH will detect both types of degradation before the breakdown occurs. Simulations of degradation resulting in an arc were carried out with RFH on two different vintage transmitter/line configurations by Dielectric and DACS in 2020. Since this type of simulation will always result in rapid deterioration and subsequent arc, the reaction time of RFH as compared to the reaction of the transmitter protection – which was different for the two transmitters – was of particular interest.

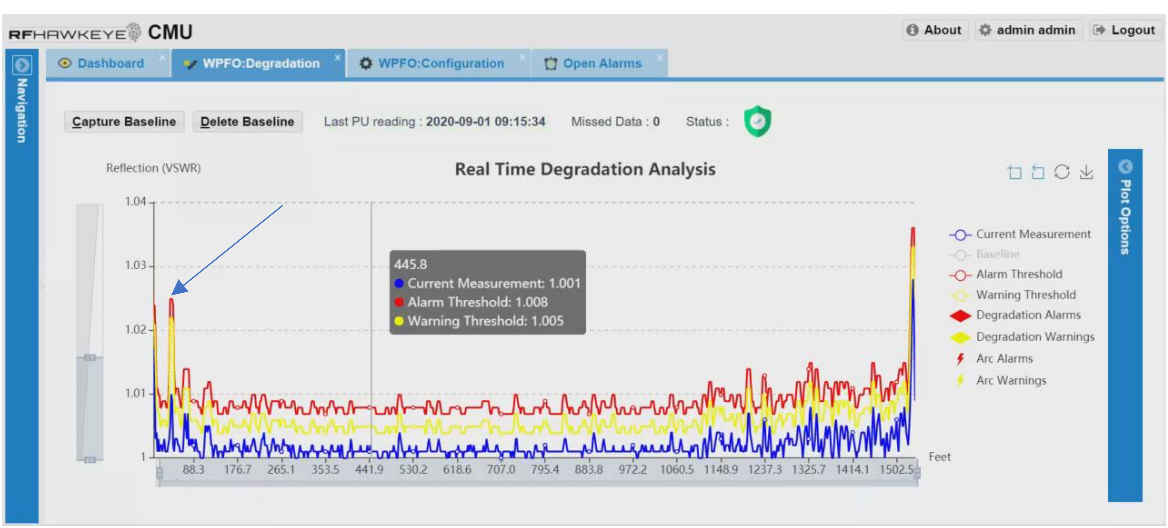
4.3.1 Arc Characterization

The first test in Dielectric's laboratory used a 10+ year old solid-state transmitter, of a make installed in many locations throughout the world, operating at 9kW in ATSC 1.0 mode into 300' of 3-1/8" 50 Ohm rigid transmission line and a test load. The transmitter VSWR circuitry was calibrated prior to the test. A probe was inserted through a tuning screw port and gradually moved closer to the inner conductor until an arc was heard and displayed on an oscilloscope connected to a directional coupler displaying forward and reflected power. The plot below has a horizontal time scale of 1 second/division. The yellow trace is the forward power and the green trace is the reflected power at the transmitter. When the arc initiates (rapid expansion of green trace) the transmitter continues to deliver power for several seconds before complete shutdown. It appears that foldback is initiated in one or more amplifiers at the onset of the arc. The purpose of this test was not to test the speed of the transmitter circuitry, more to illustrate what may well occur in real-life situations, leaving the operator with no indication of what might have caused the shutdown. In all likelihood the transmitter will recycle power into the line causing further shutdowns and damage. The photo on the right of the display shows the damage to the test probe – the tip melted. There was also damage to the inner conductor of the line.

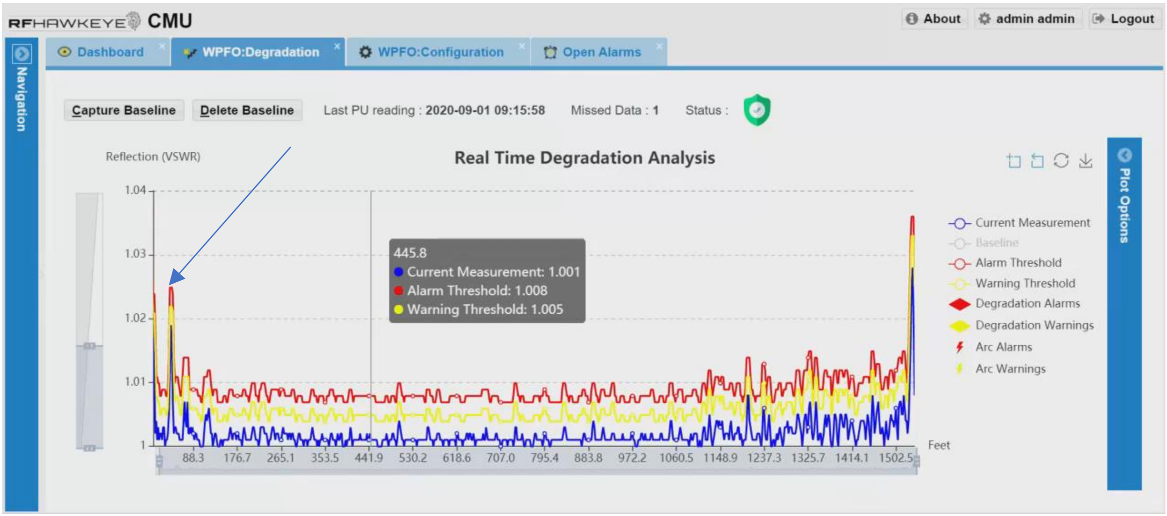


4.3.2 Arc Detection Under High Power Conditions

The second test was carried out at a high power TV station which operates a new solid-state transmitter at 58kW ATSC 1.0 average power into approximately 1,600’ of 6-1/8” 75 Ohm line terminated with a pylon antenna. Special permission for the testing was granted by the station owner. In this test, the special probe was inserted in an elbow at the end of the horizontal run, approximately 50’ from the Coupling Unit (CU) of RFHAWKEYE. Transmitter calibration was confirmed and the line then depressurized to insert the probe. The transmitter VSWR did not change with the probe in the fully retracted position. As the probe was inserted the RFHAWKEYE monitored the line and logged warnings and then alarms as the VSWR at that location exceeded the corresponding preset values for warning and alarm (warning shown in yellow and alarm in red on the images of RFH display). At a certain penetration of the probe the arc was heard and was recorded by RFH, fractions of a second prior to the transmitter cutting the RF power – see sequence of displays below.

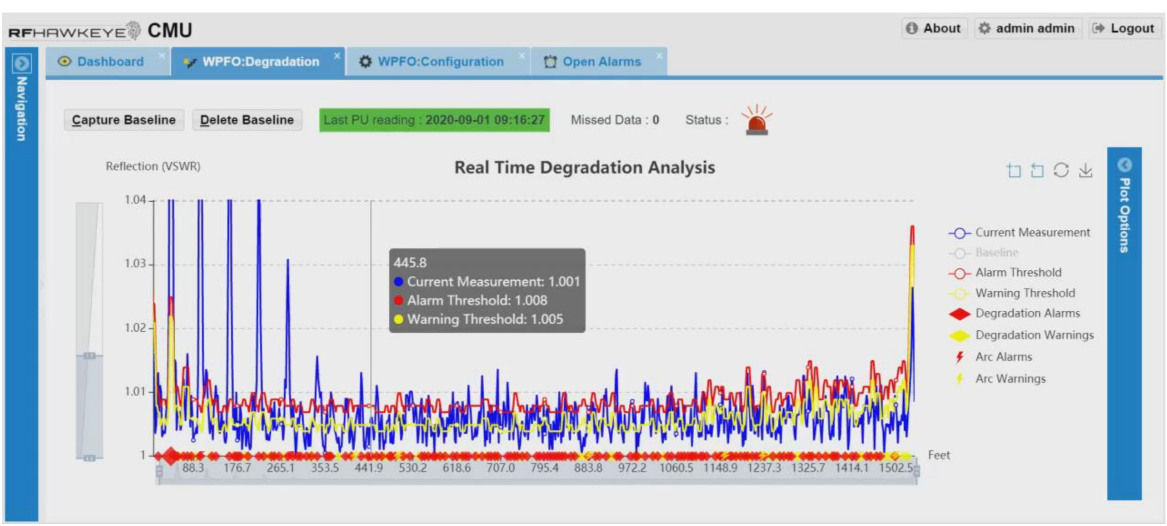


RFH Degradation Plot Under Normal Operation with Current Measurement, Warning Threshold, and Alarm Threshold Traces. Arrow Indicates Location of Probe Insertion.



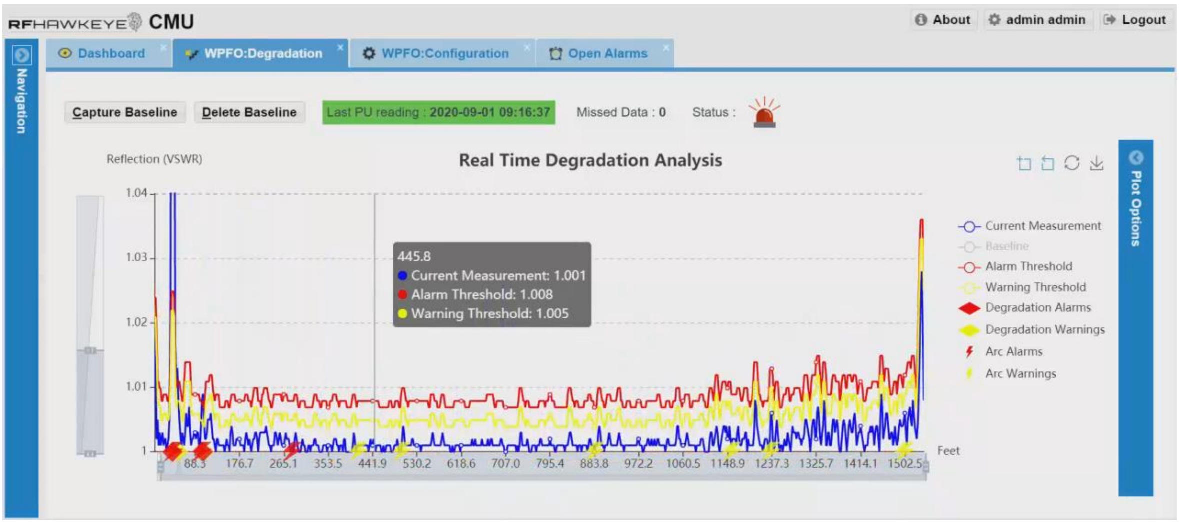
RFH Degradation Plot Showing Elevated Degradation as the Probe is Inserted

RFH Degradation Plot Showing Degradation Alarm Status as Measurement Exceeds Alarm Threshold



RFH Degradation Plot at instant of Arc Occurrence and Transient Response Beyond the Arc

Note: the transient response of RFH at the time of the arc is the characteristic signature of multiple reflections between the arc itself and the transmitter. This response has a very short duration, fractions of a second, settling into the final display of the arc event at the probe location. The current software version identifies the original event and masks the transient reflections.



RFH Degradation Plot Showing Transient Response Disappearance and Degradation Alarm Active

The new solid-state transmitter did shut-down during the test. The shutdown time was not measured but appeared to be very rapid. This should not be taken as a comparison of the response times of the two transmitters used in the tests, the manual nature of the simulation has many variables - as do real arc events in the field. Regardless, in this case, no damage of the transmission line at the test probe location was observed.

In summary, RFHAWKEYE displayed the degradation in VSWR as the probe was inserted and triggered a warning and an alarm before the actual arc occurred. The response of RFH to the arc demonstrated a repeatable characteristic signature and, more importantly, provided the operator with information on what happened and where it happened. This was a simulation of an arc under controlled conditions, which are not likely to occur in the wild. However, the series of displays of the response of RFH to this test clearly show that degradation which, if undetected, will lead to arcing will in fact be detected and displayed by RFH. This affords the opportunity to interface RFH to the transmitter interlocks in a manner which prevents extensive damage occurring.

5 Conclusions

RFHAWKEYE moves the monitoring of broadcast transmission systems from a reactive mode to a proactive mode enabling better protection of the transmission system as well as increasing the overall reliability and safety of the site.

Monitoring of the entire RF transmission system 24/7 at full RF power, using RFHAWKEYE, can warn the operator of locations of small changes and send warnings and alarms when the changes exceed the thresholds, but before they could cause extensive damage. It provides historical data on the system condition allowing trends to be identified without the need for a visit by a technician to sweep the line and verify normal operation or, in the case of an alarm, determine where the issue is located thus reducing maintenance and/or repair costs and off-air time.

RFHAWKEYE is a monitoring system which operates independently of the broadcast standard in use, thus providing broadcasters with valuable information on, and protection of, their RF systems long into the future.

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