ON-LINE MONITORING OF TURBO-GENERATOR VIBRATION IN KAKRAPAR-1

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On-line monitoring offers immediate information about the condition of a turbo-generator. It has obvious economic advantages because, while the power is being generated, the diagnosis is also carried out at the same time. In the increasing cost conscious market, reliability of steam turbine is of fundamental importance to the power industry.

All large power steam turbines are multi-cylinder machines having several rotors successively joined. The totality of the individual cylinder rotors joined together by means of couplings is named the turbine rotor. Commonly, this term implies the generator too. Each individual rotor is normally supported by its own journal bearings, which are fastened to the turbine foundation beams. The spring properties of these supports influence the turbine vibration characteristics.

The rotor vibration largely ensues from some deviations or inaccuracy in manufacturing or assemblage of the turbine, as well as unfavourable variations of its condition during operation (Fig.1). Such characteristics, measured and constructed for the individual bearings of the same turbine, are different, reflecting the different influences of the diverse rotors. The totality of these spectrums for all the turbine bearings forms the vibration signatures of the turbine. Signature analysis makes it possible in principle to diagnose the cause for worsening turbine vibration conditions. An online vibration monitoring system, which can offer an integrated study of turbine vibration characteristics, plays an all-important role in ensuring overall safety, reliability and economics of the plant.

With the aim to address this urgent need for on-line health monitoring of the Turbo-Generator (TG), a programme was initiated to develop and install an On-line Vibration Monitoring System in Kakrapar-1 (Fig. 2). The principal components of the system are: the front-end instrumentation consisting of transducers and signal conditioners for vibration and process parameters, a middle unit of data acquisition system and the back end data analysis and interpretation system. The main objective of the overall system is to inform the operator at any desired time about the health of the turbo-generator in the form of long term and short term trends and store all the raw data during any major transient in the plant for post processing. In addition, the system must offer diagnosis at any selected time to make corrections at the next opportunity. The main features of these three components of the system are covered below.

Front-end Instrumentation

The front-end instrumentation consists of transducers and signal conditioning electronics for measuring TG vibration and process signals. The turbo-generator in Kakrapar-1 consists of one high-pressure rotor (HP), one double flow low-pressure rotor (LP) and one generator rotor. The coupled rotor system is supported on six journal bearings instrumented with absolute velocity transducer as a standard instrumentation. The LP and generator bearings are instrumented with three velocity transducers for measuring horizontal, vertical and axial bearing vibrations. These bearing vibration signals are connected to the turbovisory panel in the plant. The signal tapping points available in the turbovisory panel are wired to the Fast Data Acquisition System (FDAS).

For monitoring shaft vibration, eddy current displacement transducers were installed on LP and generator bearings. The shaft vibration signals were directly connected to the data acquisition system.
Fifteen relevant TG process parameters were identified and were connected to the data acquisition system. The most important ones of these are generator power, turbine speed, condenser vacuum and shaft/casing differential expansion.

**Fast Data Acquisition System (FDAS)**

FDAS acquires and stores TG vibration data and the associated process parameters (Fig. 3 & 4). Twenty vibration signals and 15 process signals are connected to FDAS. The data acquisition is triggered whenever an event of any vibration signal crossing its
set threshold level occurs. The data acquisition unit simultaneously acquires 20 vibration signals at a rate of 5000 samples/sec and 15 process signals at a rate of 100 samples/sec. For all the vibration channels, 250 msec pre-event and 750 msec post-event data are acquired.

The data acquisition unit uses two Intel-8086 based microcomputer systems. Suitable hardware for signal conditioning and for evaluating RMS value of vibration signals is also provided. 8th Order antialiasing low-pass filters with cutoff frequency of 1 kHz have been employed for each vibration signal. The two microcomputers are connected to a PC through a high speed LAN for transferring the acquired data to the hard disk for storage and analysis. The PC provides operator interface to the system and facility to view the acquired data both in time and frequency domain.

Each vibration channel can be set with its own RMS threshold level depending on the actual level of vibration. Whenever the vibration level in any of the 20 vibration channels exceeds its threshold level, 250 msec pre-event and 750 msec post-event data of all the 20 vibration channels are transferred to the PC through LAN and the event time is recorded. In the case of 15 process signals, 39.250-sec pre-event data and 750 msec post-event data are transferred. The information pertaining to that vibration channel which had crossed its threshold level is also transmitted to the PC. Whenever the event of threshold-level crossing occurs, the threshold level of the concerned signal is increased automatically by 10% to avoid flooding of data to PC. Threshold levels of all vibration channels can be viewed by the operator and changed, if needed, under password control. It is also possible for the operator to demand the current vibration and process data at any time of the day (Fig. 5).

For on-line vibration diagnosis by Expert System, FDAS acquires 1 second vibration data and 40 sec process data every hour and transfers these data to Expert System PC. These hourly data transferred to the Expert System are treated as base data.
Fig. 5  Trend plots of vibration and process signals

Fig. 6  Time signal display from Expert System
Data Analysis and Interpretation System (Expert System)

The functions of data analysis, data interpretation and diagnosis are performed by a PC-based Expert System, which is directly connected to FDAS through high speed LAN. The Expert System is an on-line software which analyses baseline vibration data in time and frequency domain. The Expert System consists of two software modules: On-line Expert System (OLES), and Operator Support and Backup Data Display (OSBUDD). OLES reads the acquired signals and analyses them using the knowledge base databank built on Sohre’s distress chart. OLES then lists five most probable causes for excessive vibration. It also trends all vibration and process data for continuous monitoring (Fig. 6).

OLES has an in-built function to check if FDAS is sending any fresh data for processing. The data are checked for acceptable quality by performing signal-to-noise ratio and coherence analysis. The data are stamped with arrival time and are converted into a binary format, which is stored in a well-defined directory structure.

After performing FFT and updating the trend plot, OLES contacts the knowledge base which compares the current FFT signals with healthy FFT compiled over a period of more than two years of monitoring. When amplitude of any particular frequency component crosses the corresponding healthy value, the details of the cross over is referred to the knowledge base built on Sohre’s distress chart. OLES then gives five possible causes for the excessive vibration, taking into account the direction and location of the excessive vibration measurement (Fig. 7).
OSBUDD is a dedicated operator interface module that supplements OLES. It allows the operator to view any of the past and current data without interfering with the analysis activity of OLES. OSBUDD shows the raw signal in time domain in the backdrop of colour bands indicating the severity of vibration according to ISO standard for 3000 rpm machinery. It also shows frequency plot with a band enveloping the major frequency components. The enveloping band gives the safe level for each frequency component evolved over a long period of monitoring. OSBUDD shows trend plots of RMS values of vibration signals and amplitudes of major frequency components. The trend can be seen for the past 24 hrs, 7 days, 1 month or 1 year. The trend of a selected process parameter is also shown along with the trend of vibration signals. For shaft vibration diagnosis, OSBUDD additionally shows orbit plots. All the processed data, trends, orbit plots and time signal can be stored in hard disk or copied on a CD. There is a provision to take hard copies of these plots.

**System Commissioning at Kakrapar-1**

The individual components of the monitoring system were commissioned in a phased manner. Wiring for the front-end instrumentation was completed during one of the plant shut down periods. Shaft sensors were installed and wired. Fully tested FDAS was then installed, wired and commissioned in August 1997.

TG vibration and process data acquired regularly by FDAS were stored in cartridge tapes and CDs. These tapes and CDs were routinely sent to IIT, Delhi, for development of the Expert System software. Different stages of development of Expert System software were routinely reviewed. Several software modules not originally included for development were added to make the package operator friendly. The fully tested Expert System was integrated with FDAS in March 2000. All the components of the monitoring system are performing satisfactorily at Kakrapar-1. The plant engineers and operators have been given adequate training for effectively using the system and to attend to any maintenance work.

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