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ORIGINAL CONTRIBUTION

Channel Efficiency with Security Enhancement for Remote Condition Monitoring of Multi Machine System Using Hybrid Huffman Coding

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Abstract This paper presents a novel scheme of remote condition monitoring of multi machine system where a secured and coded data of induction machine with different parameters is communicated between a state-of-the-art dedicated hardware Units (DHU) installed at the machine terminal and a centralized PC based machine data management (MDM) software. The DHUs are built for acquisition of different parameters from the respective machines, and hence are placed at their nearby panels in order to acquire different parameters cost effectively during their running condition. The MDM software collects these data through a communication channel where all the DHUs are networked using RS485 protocol. Before transmitting, the parameter's related data is modified with the adoption of differential pulse coded modulation (DPCM) and Huffman coding technique. It is further encrypted with a private key where different keys are used for different DHUs. In this way a data security scheme is adopted during its passage through the communication channel in order to avoid any third party attack into the channel. The hybrid mode of DPCM and Huffman coding is chosen to reduce the data packet length. A MATLAB based simulation and its practical implementation using DHUs at three machine terminals (one healthy three phase, one healthy single phase and one faulty three phase machine) proves its efficacy and usefulness for condition based maintenance of multi machine system. The data at the central control room are decrypted and decoded using MDM software. In this work it is observed that Chanel efficiency with respect to different parameter measurements has been increased very much.

Keywords DPCM · CR · Huffman coding · DHU · MDM

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Introduction

Conditioned based maintenance (CBM) of electrical machine is a major research topic to the research community. Microcontroller and FPGA based dedicated hardware based online data acquisition system for CBM is reported in [1–3]. This type of data acquisition system deals with the parameter related sample values and those samples values are generally collected in a PC through its USB or serial port. The PC software (MATLAB, LabVIEW based) performs the required analysis to identify any incipient fault through various techniques out of which current signature analysis (CSA) using FFT [4, 5], neural networked CBM [6], multi variable supervision system [7], FPGA with fuzzy logic [8], inter turn fault using wavelet transform [9], Hilbert transform [10] are remarkable. Due to its predictive nature the use of condition monitoring allows maintenance to be scheduled or other action to be taken to prevent failure and avoid its consequences.

Besides, for remotely located machine, the parameters like voltage, current, power, frequency, temperature, speed, vibration etc. acquired at the local site of the machine, are transmitted to the remote PC for monitoring purposes. The transmission medium may be either wired or wireless and such a wireless data transmission by DPCM and empirical mode decomposition (EMD) is reported in [11]. Moreover, since multi-machines are generally used in industrial plants, multi machine monitoring in a plant/substation is becoming a very important issue. The recent advancement in information and communication technology (ICT) has added a new horizon towards this condition monitoring where the parameter acquisition systems for the machines are networked together with the central control room. But at the same time, in this networked data acquisition and control process, security issues are becoming a new challenge to the engineers and scientists. There are several incidents worldwide where the many process control plants have been attacked by the hackers, one such is reported in [12]. For a multi-machine monitoring system, large volume of data is required to be communicated for their almost real time monitoring and hence large band width network is essential. In order to alleviate these requirements, data compression techniques are adopted for such type of continuous real time data communication. Compression of data is not only reducing the data size to increase the spectral efficiency [13] of communication link but also increases data security [14, 15].

Data compression technique is mainly classified into two types, namely, lossless compression technique and lossy compression technique. Among lossless compression technique Huffman compression [16], adaptive Huffman compression, LZ Welch [17], run-length encoding [18] etc. are used. The most popularly used lossy data compression techniques are differential pulse code modulation (DPCM) [19, 20] and wavelet [21] compression. It is seen that the compression ratio, particularly for Huffman coding, increases with the similarity in data structure. For a continuous varying data structure, like a data set for sine wave acquisition, compression ratio is very poor. Since DPCM can bring some similarity in such a continuous varying sinusoidal data set, hybrid of DPCM and Huffman coding will definitely improve the compression ratio as security level. On the other hand, the security can further be enhanced with the encryption technology which is frequently used in ICT applications [22]. In [23] the authors described about the formation of a virtual private network (VPN) utilizing encryption and decryption on data communication for its economic, high-efficient and reliable low cost network based power system protection.

So, motivated with these background technology, in this paper an attempt has been made to develop a multi machine condition monitoring system consisting of three induction machines of which one is three phase healthy machine, one single phase healthy induction machine and one faulty three phase induction machine.

Brief Description of Developed Multi-Machine Monitoring System

A state-of-the-art multi-machine monitoring system for three machines is developed with wired networking and installed at our SAP laboratory. A schematic diagram of the developed system is shown in Fig. 1.

Multi-Machine Data Acquisition System and Networking

As shown, each machine is interfaced with a dedicated hardware unit (DHU) where each DHU performs the task of machines parameters related data (voltage, current and speed signal) acquisition. Once the data acquisition for a line cycle is completed, the hybrid coding scheme starts performing following the Eq. (11) as described in the subsequent sections and finally a data packet is kept ready in its memory after its encryption with the unique private key. The final data packet is getting refreshed on each and every line cycle.

In this setup, three DHUs are used for three machines and all DHUs are connected to the central PC using RS485 based network communication protocol with a bus topology configuration. The network can be extended for more number of DHUs by a simple interfacing of it to the existing bus. The PC is used as a central and master node to control the flow of the data through the network. Since microcontroller (PIC 18F4520) works on TTL logic, a TTL to RS485 or vice versa converter is essential to build up the network. On the PC end, PC utilizes RS232 levels and hence RS232 to TTL and then TTL to RS485 converter is utilized.

Each DHU is associated with a unique MAC address and a particular private key for data encryption. When a particular machine is needed to be monitored, PC sends command, through the transmitting path/channel, by communicating the MAC address of that particular DHU following packet format as mentioned in Fig. 2. All the DHUs receive this command and the particular DHU, whose MAC address is matched, responds to this call and takes out the control of the bus to connect its own transmitting line to the receiving line of PC and transmits the data following packet format as mentioned [(Eq. (13)]. All other DHUs relinquish the bus line to avoid any probable bus contention.

At the PC end a state-of-the art software is written which performs the task for data retrieval. Firstly, it decrypts the received coded data by the private key, and then checks the authenticity of the data for a particular machine. It then

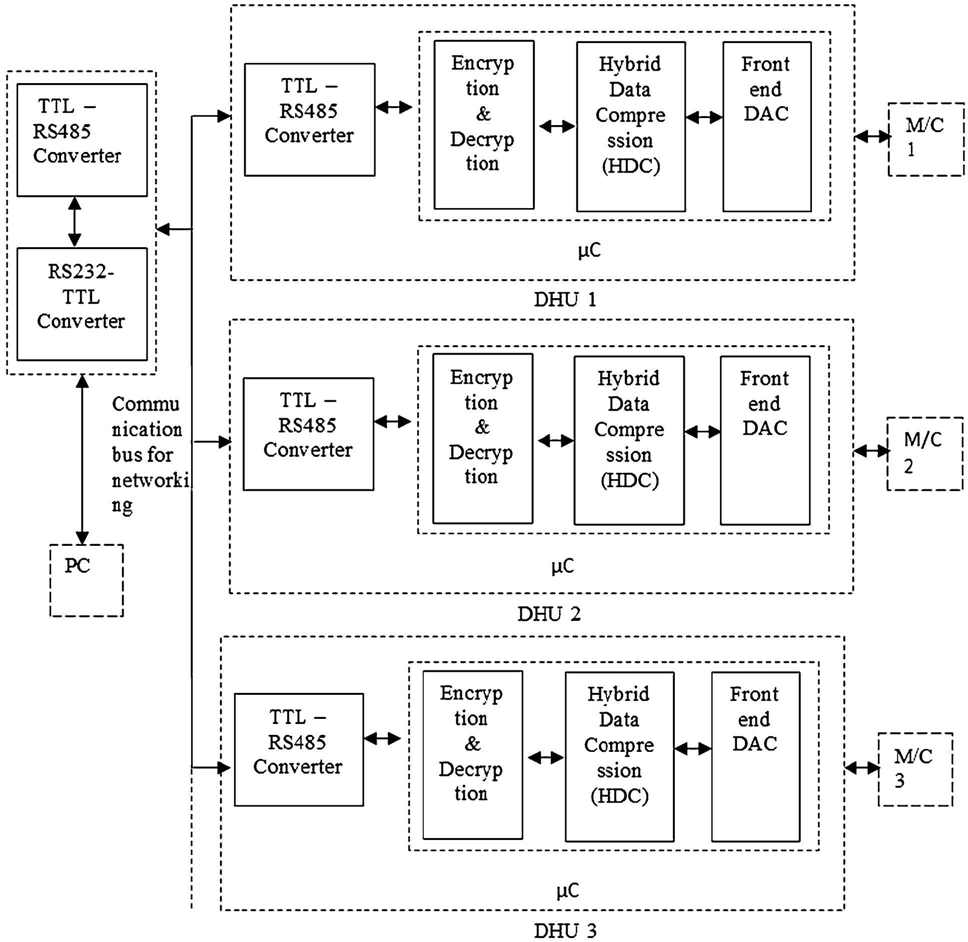


Fig. 1 RS485 based networking of multi-machine CBM

MAC	Command Type	Set parameter (Optional)	Checksum
1 Packet			

Fig. 2 PC to DHU data packet format

decomposes the data by Huffman and reverse order decoding technique.

Hardware for Parameter Acquisition of Each Machine

The DHU unit is developed in order to measure the voltage, current and speed parameters of a machine which are essential to monitor the healthy condition of it. Each of these DHUs (Fig. 3) is interfaced with different sensors like potential transformer (PT) for voltage measurement, hall sensor (HS) for current measurement. Voltage and current signals from each machine is converted to digital signal through ADC. Input voltage to the machine is reduced for the measurement purpose by potential transformer (PT) and potential divider (PD), compatible to ADC input voltage level. The transformation ratio from input to

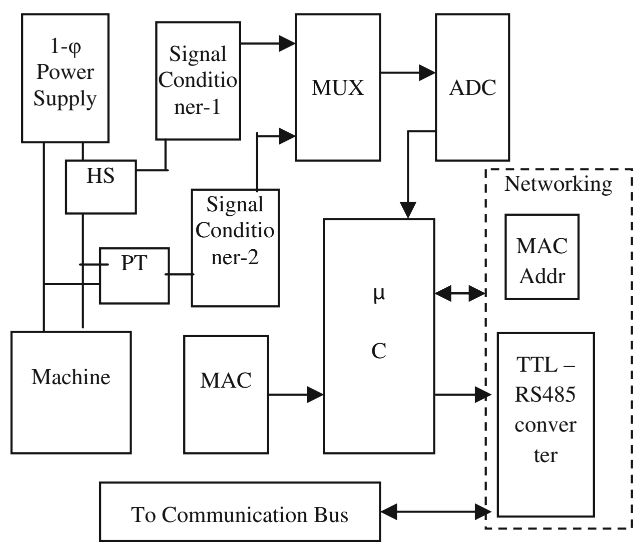


Fig. 3 Schematic diagram of a particular DHU

DHU end will enable to find out the actual voltage. The measurement of current is accomplished by hall sensor (HS). The sensor's output current is converted to voltage

(V_R) by passing it through the series resistor (R). MAC address of each DHU is to be set manually with dual inline package (DIP) switch in DHU board. All these parameters value are communicated in coded form to a remote PC through this bus.

Networking Issues

Networking of the DHUs is established using RS485 Protocol with a data rate of up to 57.6 Kbps using a two pair STP cable (Shielded Twisted Pair). The DHU has the option of transmitting either single phase or three phase current signal samples along with r.m.s values of applied voltage and machine speed data each of two bytes following the packet structure as given in Fig. 4. As shown, the first byte in this structure contains the number of remaining bytes (l) within the packet, second byte contains the MAC address of the intended DHU, and from third byte hybrid Huffman coded data (HCD) sub packet is attached. The content of HCD is described in detail in Eq. (11). Two bytes of voltage data is appended after this. The MSB of upper byte of next two byte long speed data carries the no. of phase information. If MSB of upper byte of speed is one, the HCD bytes are for three phase and is to be divided by three to retrieve per phase sample values after its decoding. A checksum byte is appended at the end of the packet to check any communication error.

The number of HCD bytes within the packet is expressed in Eq. (1)

$$\mathrm{HCD} = (l + 1) - 5 \quad (1)$$

Thus this packet is a mixture of HCD coded current samples and the remaining simple data bytes.

On the other hand, the packet structure for DHU from PC is shown in Fig. 2. The command type is either for setting the upper limit of voltage, current, speed or for data request the parameters value to be set is specified in parameter column.

Bandwidth Management

Now the total number of bits (T) for such a packet to be transmitted is expressed as

$$T = (l + 1) \times f \times 10 \text{ bps} \quad (2)$$

Again, if number of machine to be monitored is 'K', the total no. of bits Tn can be expressed as Eq. (3)

l	MAC	HCD	V	Speed	Checksum
1 Packet					

Fig. 4 DHU to PC data packet format

$$T_N = K \times (l + 1) \times f \times 10 \text{ bps} \quad (3)$$

For example if sampling rate is of 5 kHz and for a 3 phase machine the number of bytes for prime values and HCD is 89, making $l = 94$.

Therefore, T becomes (95 × 50 × 10) = 47500 bytes/s = 47.5 kbps for $f = 50$ Hz. Thus for three machines to monitor, it requires 3 × 47.5 = 142.5 kbps communication speed.

This huge bandwidth requirement is managed by considering 10 cycle consecutive data for each machine instead of all 50 cycle data continuously and is refreshed at each 5 s interval. For such consideration, it is presumed that 10 cycle data over a 5 s interval is sufficient for detecting any incipient fault. With this more number of machines can be monitored by using a moderate communication speed.

Thus considering this frame with 10 line cycle data and a communication speed of 57.6 kbps, 6 number of machine can be monitored in 1 s or in other word for 5 s interval 30 machines can be monitored.

Principle of Data Encoding and Decoding Scheme

Continuous data transmission is required for plant health monitoring, which leads to large channel bandwidth as well as large memory space for data storing. This can be reduced by data compression technique. In this work, both DPCM and HC is adopted. By this hybrid encoding technique not only the data is compressed but also security feature is inherently introduced. The security is further enhanced by adopting encryption technique whereas only one unique security key is allotted for each machine.

Each DHU transmits the coded parameters through the network layer by time division multiplexing. PC receives the coded data and decrypts the data for each machine with the particular key assigned for the particular machine followed by a hybrid decompression technique. This decompression technique is encompassed by Huffman decompression and reverse order DPCM to get the original current data for each machine. The procedure of data coding and decoding has been illustrated in Fig. 5.

State-of-the-Art of Hybrid Huffman Coding

In HDC both lossy and lossless data compression techniques have been adapted successively. In this technique the current data of induction machine is coded by this hybrid coding technique. The signals consist of fundamentals as well as harmonics of several orders (third, fifth, seventh order). Hence only the r.m.s value and frequency information is not sufficient for retrieval of the original data.

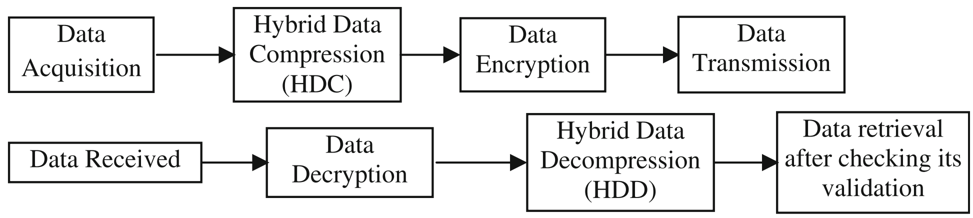


Fig. 5 Data coding and decoding flow schematic for data transmission and reception

Differential Pulse Code Modulation (DPCM)

In practice, DPCM is generally used with lossy compression techniques. Basic concept of DPCM coding a difference is based on the fact that if source signals show significant correlation between successive samples then a high volume compression can be achieved by differential operator.

In any electrical system applications typical voltage or current waveform can be expressed as sinusoidal or co-sinusoidal function as Eq. (4)

$$x(t) = M\cos 2\pi ft \tag{4}$$

where M is the magnitude of the signal; f is the frequency in continuous time domain and for discrete samples the expression is as Eq. (5)

$$x(n) = M\cos(2\pi f(n-1)T_s) \tag{5}$$

where $n = 1, 2, 3\ldots$ is the positive integer showing the successive sample numbers and T_s is the sampling interval.

The differential signal of first order can be written as

$$x_1(t) = x'(t)T_s = -M(2\pi fT_s)\sin(2\pi ft) \tag{6}$$

where T_s is the sampling interval and second order DPCM takes the form as

$$x_2(t) = x_1'(t) * T_s = -M(2\pi fT_s)^2\cos(2\pi ft) \tag{7}$$

This shows that at every differential operation the signal of each order still is either sine or cosine function which is multiplied by the factor $2\pi fT_s$. Since $T_s >> (1/f)$, hence $2\pi fT_s << 1$ Therefore the amplitude of high order signal will become very small and data samples will be compressed within a zone.

Keeping this in mind, up to second order DPCM is introduced in this Hybrid HDC technique. Based on this principle, the following technique is adapted to obtain the second order DPCM current data.

Suppose N number original current signal data sequence is $I_0 = \{i_0(n)\}$ (8)

where $n = 0, 1, 2, 3,\ldots, N-1$. The first order DPCM the data sequence is generated as given in (9).

$$I_1 = \{i_1(n)\} = \{i_0(0), i_0(n) - i_0(n+1)\} + b_1 \tag{9}$$

where i_0 (0) is the first value of I_0 data sequence. Other values are the difference of the successive data samples and b_1 is the biasing value for the 1st order DPCM.

Similarly, second order DPCM is obtained as

$$I_2 = \{i_2(n)\} = \{i_0(0), i_1(1), i_1(n) - i_1(n+1)\} + b_2 \tag{10}$$

where i_1 (1) is the second value of I_1 data sequence. Other values are the difference of the successive data samples and b_2 is the biasing value for the second order DPCM.

Huffman Coding

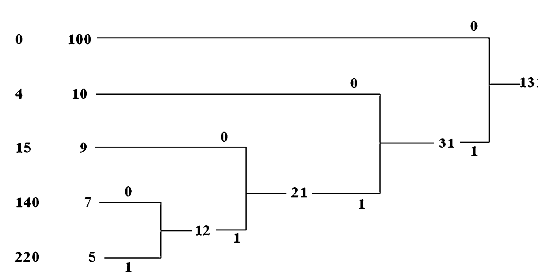
Now-a day Huffman coding algorithm, a greedy approach to generating optimal prefix codes for lossless data compression in the revolution of computer and information theory.

Huffman's algorithm is based on the idea that a variable length code should use the shortest code words for the most likely symbols and the longest code words for the least likely symbols. In this way, the average code length will be reduced. The algorithm is illustrated with the following example.

Suppose that a list consists of five primary values of data such as 0, 4, 15, 140 and 220. Each one with a frequency of

Table 1 Huffman coding example and process of building Huffman tree

Prime value	Distribution frequency	Code
0	100	0
4	10	10
15	9	110
140	7	1110
220	5	1111



occurrence, P(0) = 100, P(4) = 10, P(15) = 9, P(140) = 7, P(220) = 5. The final Huffman Coding is shown in Table 1.

The data string generated using DPCM, that is, I_2 is then coded by Huffman coding with the requisite evaluation of prime value, their distribution frequency and representing the byte values with the Huffman code bits pattern. The coded bytes are then utilized to form a part of data packet (HCD) containing no. of primary values[k], data of prime values [p_k] and the code bytes for three phase current [c_j]. The packet format is represented by a symbolic notation like

$$\mathrm{HCD} = [k][p_1]\ldots[p_k][c_0]\ldots[c_j] \tag{11}$$

Security Enhancement by Encryption

It is further encrypted with a private key where different keys are used for different DHUs. Encryption is the conversion of data into a form, called a cipher text that cannot be easily understood by unauthorized people. Encryption/decryption is especially important in communications. In order to easily recover the contents of an encrypted signal, the correct decryption key is required. Encryption involves applying an operation (an algorithm) to the data to be encrypted using the private key to make them incorrigible. The slightest algorithm (such as an exclusive OR) can make the system nearly tamper proof. Among different encryption techniques 'XOR Encryption' is used as two way encryption as it is simple and fast and easy to implement. In our secured data transmission after Hybrid Huffman Coding we have used an 8 bit private key XOR encryption to each data. The private key for every DHU here is known to respective DHU and to VB based MDM. This private key is an 8 bit number. Hence when the firmware of each DHU sends the data after Hybrid Huffman coding it performs 'XOR' of each byte with its private key. The MDM system at the receiving end again performs 'XOR' of the received data with the same private key for that particular machine. For example if the private key for a particular DHU is 55 (that is, 01010101) and if any data after Hybrid Coding is 225 (1110 0001). Then the transmitted data will be (1110 0001 + θ 0101 0101 = 1011 0100) will be 180. At the MDM system this 180 byte will again be deciphered with the help of the private key 55. And the decrypted signal value will be retrieved. Now this decrypted signal will be retrieved by Huffman decompression and reverse order DPCM. In this way the security of the transmitted data can be enhanced. The communication error can be checked using checksum error detection principle.

$$\mathrm{P} = [\mathrm{l}][\mathrm{MAC}][\mathrm{HCD}][\mathrm{V}][\mathrm{Speed}][\mathrm{Checksum}] \tag{12}$$

$$\mathrm{P}_1 = [\mathrm{P}_k]\mathrm{X}_{\mathrm{OR}}[\mathrm{P}] \tag{13}$$

where $\mathrm{P_k}$ is the private key.

Decoding Principle

Decoding is done by remote PC. The decryption operation of the received data string is made stepwise with the private key using logical operation of packet P1.

After the logical operation, the following steps are performed in order to retrieve back the original data.

1. The first byte indicates how many remaining bytes are to be decoded.
2. Checking of checksum for communication error from last byte of the packet length. If any error occurs the entire packet is discarded.
3. The second byte segregates the MAC address from the received data string indicating the machine no.
4. From the last four the voltage and speed magnitudes are evaluated.
5. Get the number of primary values from third bytes of the packet.
6. The rest bytes are HCD bytes requires Huffman decoding operation to get the DPCM encoded data bytes.
7. Reverse order DPCM up to second order produces the original data which can now be utilized for analysis purposes.

VB Based MDM System

The PC based machine data management (MDM) software for this centralized conditioned based monitoring system plays the pivotal role in receiving of compressed data from remote machine's for monitoring, diagnosing and also storing the data after decompression for future trend analysis purposes. It also helps to take the corrective measures to minimize the downtime of the process plant.

A state-of-the-art VB based software is developed as an integral part of this work. The basic role of this software is to collect the machine compressed data coming from the DHU and stored them into its memory followed by decryption of the received data by 'XOR' ing with the particular machine private key and then decompression of the decrypted data by adoption of Huffman decoding and reverse order DPCM consecutively to get the original data for displaying the general conditions of the machines as well as for analysis purposes. On analysis part, along with general condition monitoring, the software makes a database as reference. It also performs a preliminary analysis and annunciates for any primary abnormal condition that may appear during running condition. This analysis is required for fault detection occurring in an induction machine.

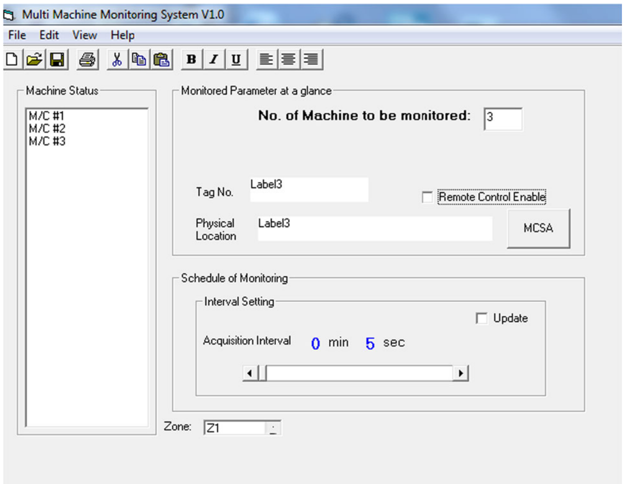


Fig. 6 GUI Front end for 'multi machine monitoring system'

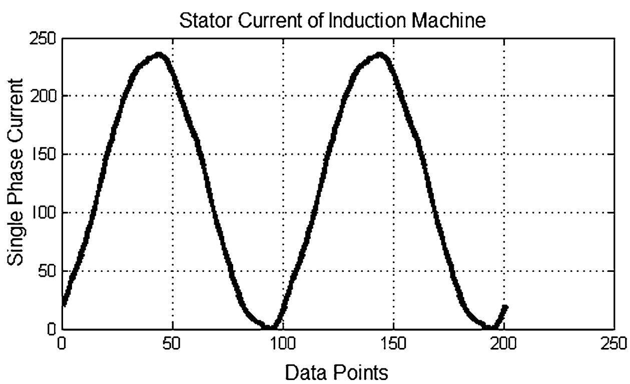


Fig. 7 Single phase stator current with 3 % THD (two cycles)

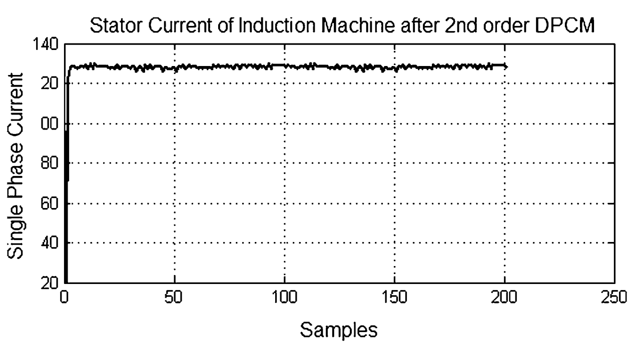


Fig. 8 Single phase Stator current after second order DPCM (two cycles)

The front end GUI for 'multi machine monitoring system' is shown in Fig. 6. The software relies upon two main files, namely, data configuration file and data storage file. The data configuration file is related to two main windows of the 'frmMain' and 'frmCapture'. The front end of the 'frmMain' window reads the data configuration file and displays the machine number, tag number, physical location of the machine and the rating (specification) details of the machines. The details of every machine in this multi machine monitoring system are also stored in this file. Machine data is acquired from 'frmCapture' pop up window pop up. The front end of this 'frmCapture' GUI is so designed that the user can select the maximum machine number and as well as the time interval based on which the individual machines can be read sequentially. The data request packet corresponding to each machine is generated and send to the machine automatically one after another. The next read sequence is started after the elapse of the specified time interval.

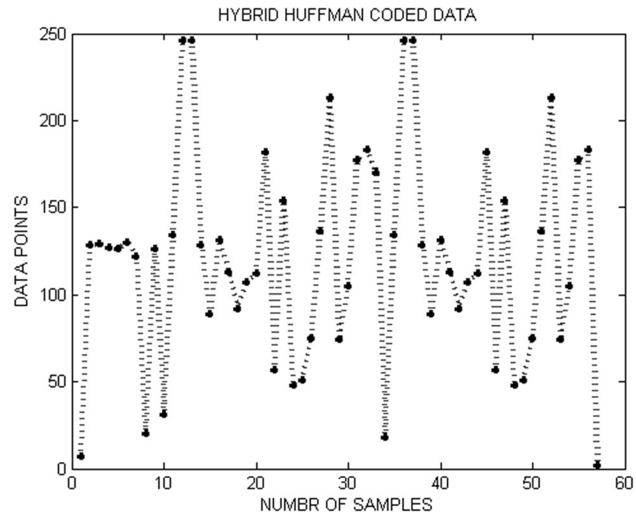


Fig. 9 Single phase stator current after hybrid HDC (two cycles)

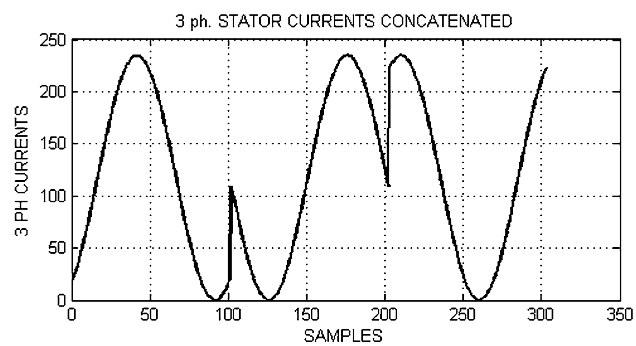


Fig. 10 Three phase stator current (one cycle) concatenated after 1st DPCM

Once a data read/capture sequence is completed for the entire machine, the data is stored in a data file. The data is then decompressed following decoding principle, as described on earlier and the MCSA principle is applied on current data of each machine to check any abnormality in its signature. If any abnormality is detected, an indication window pops up by highlighting the abnormality to draw the attention of the operator. Otherwise healthy indication is highlighted within the same window.

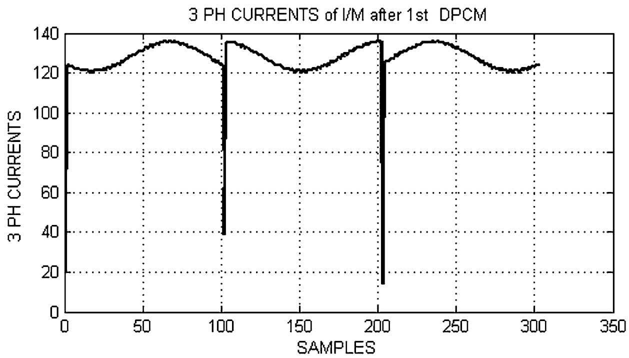


Fig. 11 Three phase Stator current after first order DPCM

The software MCSA is intelligent enough to detect the severity of fault also depending on the security of the abnormality; the STOP command can also be generated form the software and transmit to that particular machine to stop it without the intervention of human being. At the same time an SMS (optional) is generated and transmitted

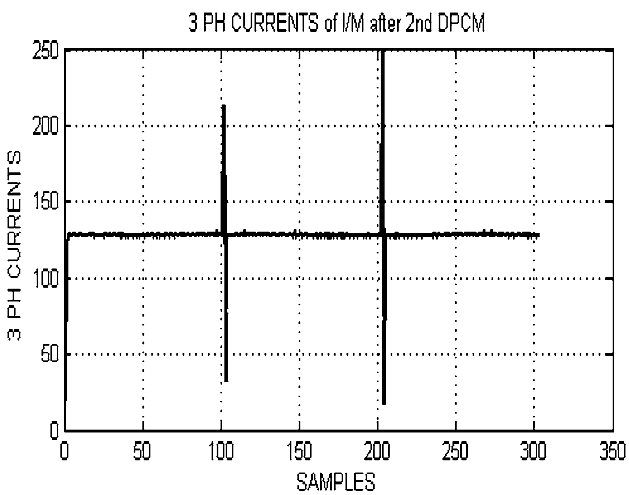


Fig. 12 Three phase stator current after second order DPCM

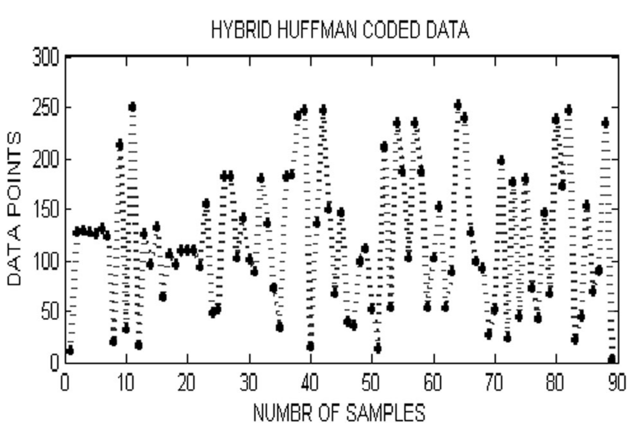


Fig. 13 Data after hybrid HDC

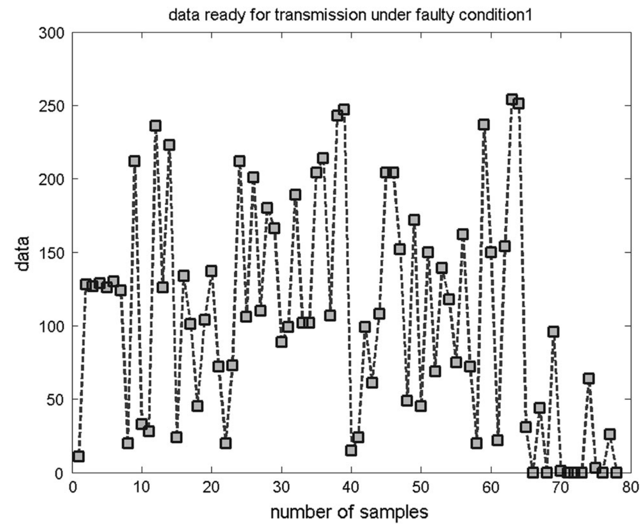


Fig. 14 Data ready for transmission under single phasing fault

to the higher authority mobile number which are pre-loaded into this software.

Results

MATLAB Based Simulation

Healthy (Single Phase) Induction Machine

In this simulation study the induction motor under test is modeled in MATLAB-SIMULINK environment. The single phase stator current is compressed by the proposed hybrid HDC technique. In this simulation, the phase current (Fig. 7), comprises of 3 % THD is considered and sampled at 5 kHz sampling rate.

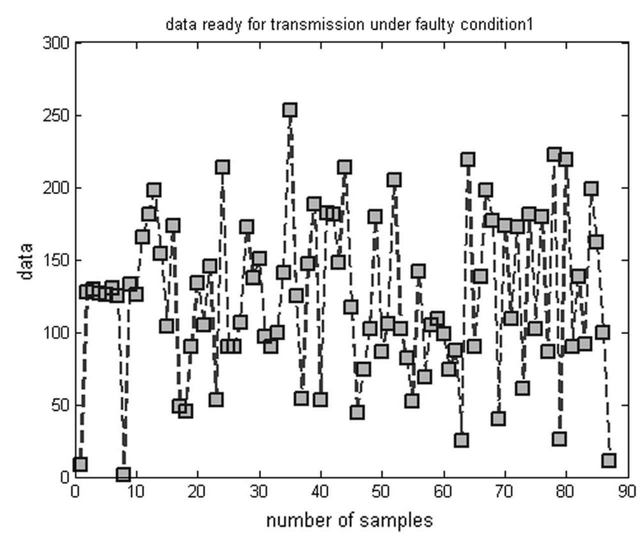


Fig. 15 Data ready for transmission under broken rotor bar fault

After second order DPCM data is compressed as shown in Fig. 8.

Then HDC the compression is improved as shown in Fig. 9.

Healthy (Three Phase) Induction Machine

In this simulation study the induction motor under test is again modeled in MATLAB-SIMULINK environment. The three phase stator currents are compressed by the proposed hybrid HDC technique. Firstly, the three phase currents are sampled at 5 kHz sampling rate. For every 20 ms three phase current data are obtained and theses current data are concatenated to form a string of 300 data samples as shown in Fig. 10.

Three phase stator current (one cycle) concatenated after first DPCM and by adding the biasing the waveform is compressed as shown in Fig. 11.

After second DPCM and by adding the respective biasing (Fig. 12) data is ready for Huffman coding. After Huffman coding it is observed that the number of compressed data has come down to a very low value (Fig. 13). Then for Hybrid HCD with second order DPCM the number of data samples is 89.

Faulty (Three Phase) Induction Machine

In this simulation study, the induction motor under test is modeled with broken rotor bar fault and single phasing fault. These two faults are typical faults those generally occur in induction motor. Prior diagnosis of these kinds of fault development may save the major fault in a plant. Hence study of theses faults with induction machine model is very much necessary.

Figure 14 shows the data stream for three phase currents in a faulty motor with single phasing fault, which is ready for transmission after the hybrid data compression. Here it is observed that the data volume has changed extensively compared to the healthy motor. These different data stream may be an indication that some fault is growing in the machine.

Figure 15 shows the data stream for three phase currents in a faulty motor with broken rotor bar fault, which is ready for transmission after the hybrid data compression. Here also it is observed that the data volume has reduced extensively compared to the healthy motor.

Hardware Implementation

Performance Study with Healthy Motor

A typical three machines (three single phase I/M) monitoring system using our own DHU is established in our Departmental 'SAP' laboratory with RS485 networking principle. The experimental set up is shown in Fig. 16.

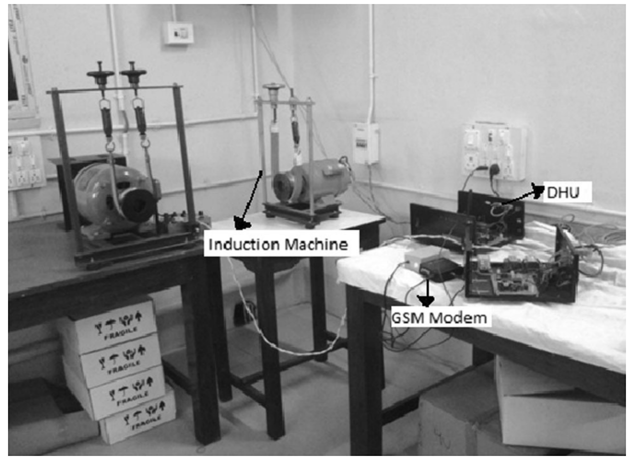


Fig. 16 Experimental set-up

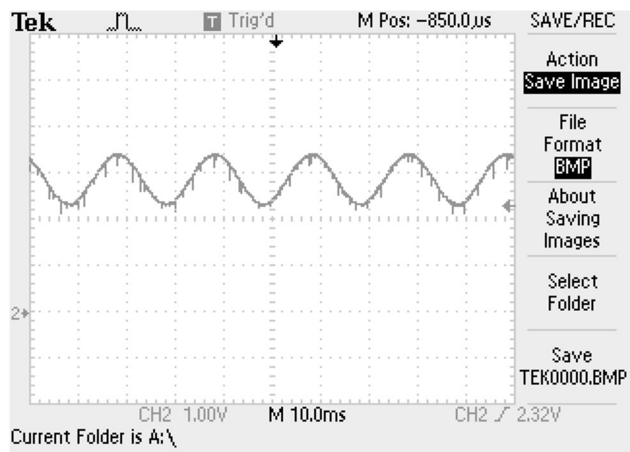


Fig. 17 Current signal waveform

Fig. 18 Packet data bit pattern of any machine

The VB based MDM software acquires the data packet out of the each DHU for a 10 consecutive line cycle for each machine at a refresh rate of 5 s. The data packet is constructed by each DHU following Eq. (13) and is sent to the MDM software when it is asked for. For testing purposes, the original data (without DPCM and HCD) is also sent to the PC. The current drawn by the machine is shown in Fig. 17, while Fig. 18 show the packet stream bit pattern at a particular instant. The packet is decoded within MDM software to retrieve back the sample values of current signal which has the exact match with the original uncompressed data. This proves the efficacy of the proposed system and it is observed that a data compression of 48 % is achieved in this case.

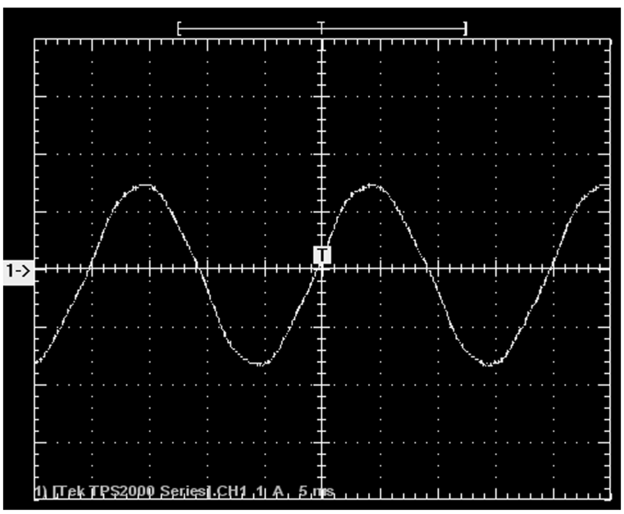


Fig. 19 Current signal waveform for one phase in no-load broken bar condition

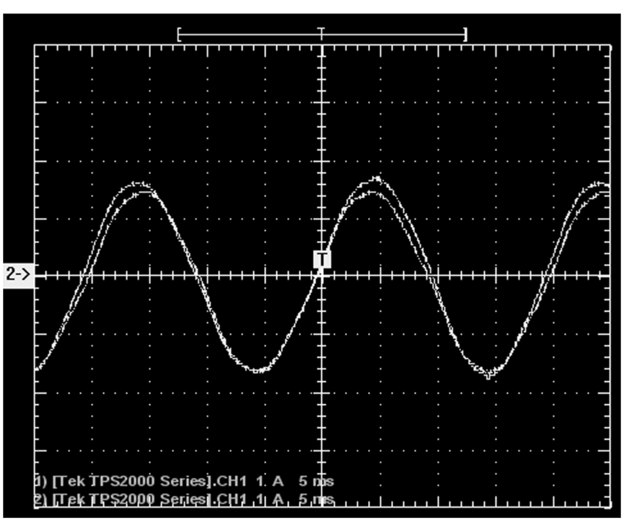


Fig. 20 Current signal waveform for one phase in partially loaded broken bar condition

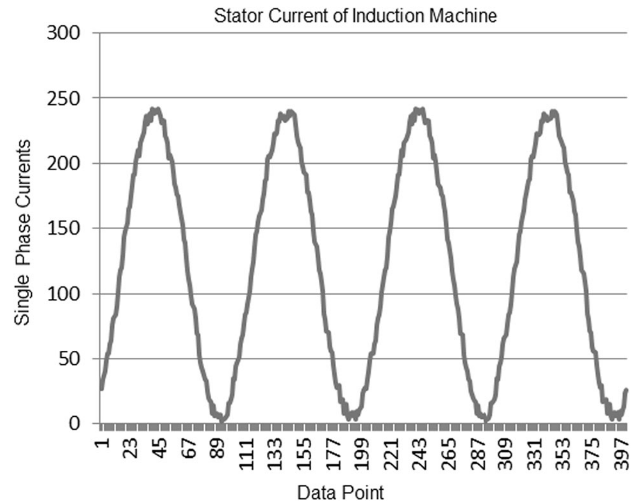


Fig. 21 Decompressed waveform for no-load broken bar motor

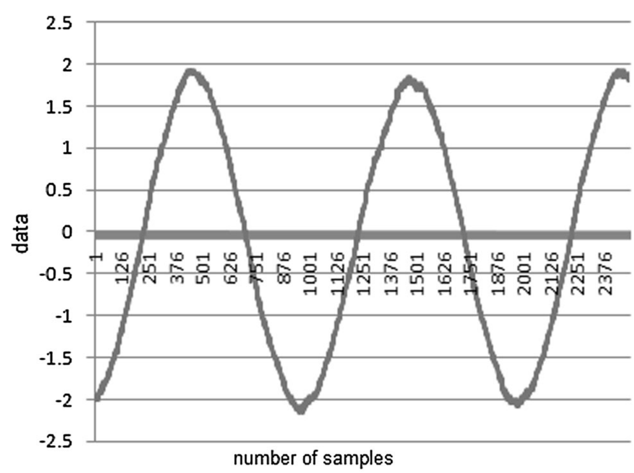


Fig. 22 Decompressed waveform for partially loaded broken bar motor

Performance Study with Faulty Motor

The rotor of one healthy motor is replaced by a rotor with only one bar in broken condition (broken rotor bar). Figs. 19 and 20 represent the current signature waveform of this broken bar motor under no-load and a partial load conditions. In the MDM software, Figs. 21 and 22 show the retrieval of compressed data after their decompression.

It is observed that in no-load broken bar condition the original 100 bytes data comes to 49 bytes data after hybrid compression. Thus a data compression of 50 % is achieved and the compressed data stream is shown in Fig. 23.

Similarly, a data compression of nearly 58 % is achieved in partially loaded condition and the compressed data stream is shown for faulty machine in Fig. 24.

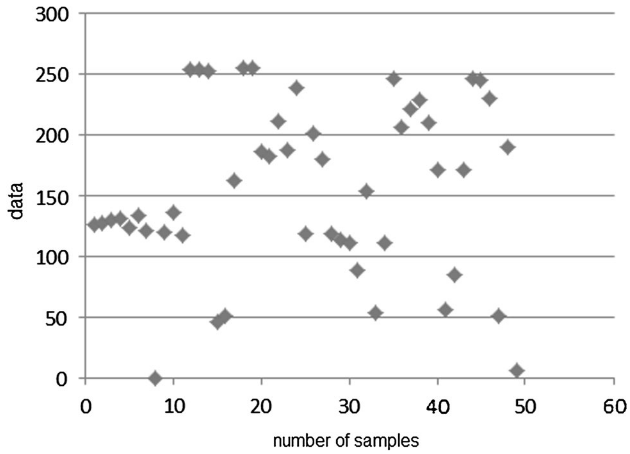


Fig. 23 HDC data stream ready for transmission for no-load test

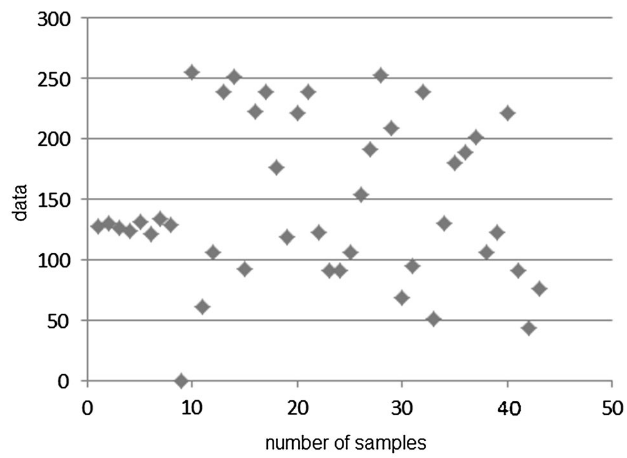


Fig. 24 After HDC data stream ready for transmission for partially loaded test

Discussion

The novelty of this work is that a second order DPCM technique is adopted along with Huffman coding scheme in order to have both compression and security in data transmission in a machine monitoring system.

The Huffman coding data compression case studies are made based on the samples values of analog current signal containing harmonics up to 5th order with THD 3 %. As shown the compression is made effective as the wave from is less polluted with harmonic. For higher pollution it is expended from its original data size.

The possibility of third party attack during data communication is minimized by utilizing a private key encoding scheme. However with the adoption of DPCM additional security features are added with this coding scheme even if the data is not compressed always for higher order pollution.

By incorporating the time division multiplexing of the 10 line cycle coded data, the communication bandwidth is reduced for multi machine monitoring, as described earlier.

The transient effects are reduced by incorporating a low pass filter signal conditioner at the front end of the DHU. This improves the system performance by reducing the error in sampling the current signal.

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