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APPLICATION OF A NEW CLASS OF SEC-DED-BED CODES IN INTELLIGENT INSTRUMENTATION

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Abstract: *Electric power system monitoring is in most cases reduced to tracking only extremely dangerous situations, but not those that are not yet drastically developed. The possibility of detecting potentially dangerous situations and a fast notification mechanism represent one of the main challenges in terms of securing the most reliable electric power system operation. In this paper the principle of work of the communication subsystem of the integrated instrument for harmonics measurement (IMH), i.e. a device that in a very simple way detects all threatening situations in a system, is presented. Besides operating in the certain frequency domain, the advantage of the IMH instrument, compared to devices of similar purpose, lies also in a fast system of notification based on sending packets protected by a new class of SEC-DED-BED codes. Apart from a high level of data integrity, the mentioned codes offer also the possibility of adapting the IMH instrument to conditions within a communication channel. Depending on the type of medium, the packet length can vary from 128 bits in case of a high noise level, up to 524288 bits, in case of a very low noise level.*

Key Words: ***Harmonic measurement, fault recording, SEC-DED-BED codes, data transmission.***

1. INTRODUCTION

An adequate power supply represents the main condition for correct functioning of industrial, communication and transportation systems, etc. In order to regulate this field by law, the European norm BS EN 50160:2000 strictly defines the limit values for different occurrences that can affect the quality of electric energy. However, the presence of a great number of non-resistive consumers, has been always threatening the normal operation of certain parts of electric power system and in some situations, also the functioning of the system itself. To prevent this from happening, a few years ago a large number of devices have been developed, that beside detection of unusual states within the system also have fault recording function [1], [2]. The device that is commonly used in Serbia for this is osciloperturbograph. However, its basic flaw is seen in its ties to protecting relay, so that with this device several periods of network voltage, power before malfunction and failure itself can be recorded, but not the potentially dangerous situations. Considering that this fact significantly limits the quality analysis of power supply, a certain number of autonomous devices that can define classes of triggering events which are detected and recorded, has appeared on the market. One of them is the integrated instrument for harmonics measurement (IMH) [3], [4], i.e. a device which by directly measuring 50 harmonics within a period in a very simple way detects all threatening situations. In addition to working in a frequency domain, the advantage of IMH instrument, in relation to other devices of the similar purpose is also in the realisation of communication subsystem, where the measured data is protected with a very high level of integrity using the new class of SEC-DED-BED codes. Apart from that, an additional advantage of using the mentioned code lies in the possibility of adapting the IMH instrument to communication channel conditions. For example, if multi-bit errors occur, on receipt of the request for retransmission, the IMH instrument may shorten the data packet for one of the pre-defined lengths, encoding the actual size in appropriate header field.

2. BASICS OF INTEGRATED INSTRUMENT FOR HARMONICS MEASUREMENT

The IMH instrument is based on the generalized low-frequency stochastic true-RMS instrument which is presented in detail [3]. Its block schematic is presented in Fig. 1.

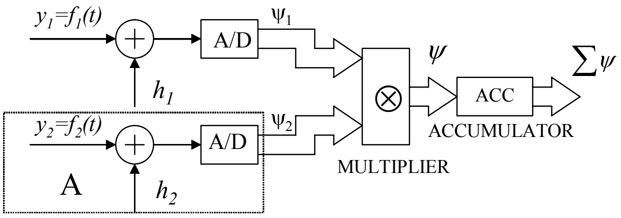


Fig. 1. *Generalized low frequency stochastic true RMS instrument*

Signals h_1 and h_2 are uniform, non – correlated dither signals, superimposed onto the input signals y_1 and y_2, respectively. This instrument obtains measurement results during $t_2 - t_1$ measurement time given by:

$$\bar{\psi} = \frac{1}{t_2 - t_1}\int_{t1}^{t2} f_1(t) f_2(t)\, dt \tag{1}$$

while the variance of its measurement error is defined by $e = \psi - y_1 y_2$ and it is given by:

$$\sigma_{\bar{e}}^2 = \frac{\sigma_e^2}{N} \le \frac{\sigma_s^2}{N} \tag{2}$$

where N is the number of samples in the measurement interval $t_2 - t_1$, while the stochastic variance is determined by the quantum of applied A/D converters (Δ) and the norm of the two internal signals:

$$\sigma_s^2 = \frac{\Delta^2}{4}\frac{1}{t_2 - t_1}\int_{t1}^{t2}[f_1^2(t) + f_2^2(t)]\,dt + \frac{\Delta^4}{16} \tag{3}$$

Harmonic components can be measured if sum of the signals y_2 and h_2 in Fig.1. is replaced by memorized samples of this sum. This can be done, since signal y_2 is the base function from the orthogonal base function set, so y_2 is known in advance. If $y_2 = R\cdot\cos(i\omega t)$ then the average value in the accumulator in Fig 1. is

$$\bar{\psi} = \frac{1}{T}\int_0^T f_1(t)\cdot R\cdot\cos(i\omega t)\,dt = R\cdot\frac{a_i}{2}, (i = 0,1,2,...,n) \tag{4}$$

In this equation R represents the signal range, i harmonic order, ω fundamental frequency, and a_i cosine component of i-th harmonic

$$a_i = \frac{2}{T}\int_0^T f_1(t)\cdot\cos(i\omega t)\,dt \tag{5}$$

this means that (5) gives one-half of an i–th cosine coefficient of a trigonometric polynomial, multiplied by a range value. If $y_2 = R\cdot\sin(i\omega t)$ then the average value in the accumulator in Fig 1. is

$$\bar{\psi} = \frac{1}{T}\int_0^T f_1(t)\cdot R\cdot\sin(i\omega t)\,dt = R\cdot\frac{b_i}{2}, (i = 1,2,...,n) \tag{6}$$

and b_i is sine component of i-th harmonic

$$b_i = \frac{2}{T}\int_0^T f_1(t)\cdot\sin(i\omega t)\,dt \tag{7}$$

consequently (7) gives one-half of an i–th sine coefficient of a trigonometric polynomial, multiplied by a range value. From (5) and (7) cosine and sine component of i-th harmonic can be easily obtained, which is enough for calculating the amplitude and the phase angle of each harmonic.

However, although with the use of the IMH instrument we can measure 50 harmonics per one input and in one period, for purposes of tracking the electro-energetic system's state, amplitude and phase values of first 10-12 harmonics are enough. By comparison with standard fault recorders (FR), which take 256 values per period, this principle of work does not only lead to significant savings of memory resources, but also to a much faster mechanism of detecting system malfunctions. Namely, with standard FR it is necessary to compare values of 256 numbers in two adjacent periods, while with the IMH instrument that procedure is mostly reduced to comparing the values of 20-24 numbers.

3. IMH INSTRUMENT COMMUNICATION SUBSYSTEM AND DATA PROTECTION

For purposes of providing data integrity, within the communication subsystem of the IMH instrument, the new class of SEC-DED-BED codes is used, i.e. codes which can correct single bit errors and detect all double bit errors, i.e. error packets b bit in length. In order to explain they functionality, let us assume that data word is made by a sequence of k bytes ($k \le 2^{b-1}$), while every byte consists of b bits (Fig. 2.).

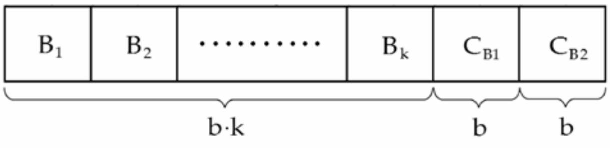


Fig. 2. *The code word structure*

In that case, the procedure of forming check-bytes C_{B1} and C_{B2} implies the use of following expressions

$$\mathrm{C_{B1}} = B_1 \oplus B_2 \oplus B_3 \oplus \ldots \oplus B_k = \sum_{i=1}^{k} B_i \bmod (2) \tag{8}$$

$$\mathrm{C_{B2}} = [1\cdot p_1 + \ldots + k\cdot p_k] \bmod (2^b) = \sum_{i=1}^{k} i\cdot p_i \bmod (2^b) \tag{9}$$

where $\oplus$ represents XOR operation on byte B_i, while the value $p_i \in [0, 1]$ is a result of a horizontal parity check on bits b_j inside B_i, i.e.

$$p_i = \sum_{j=1}^{b} b_j \bmod (2), \quad b_j \in B_i \tag{10}$$

On the receiving side using identical methods we calculate the values

$$\hat{\mathrm{C}}_{\mathrm{B1}} = \hat{B}_1 \oplus \hat{B}_2 \oplus \hat{B}_3 \oplus \ldots \oplus \hat{B}_k = \sum_{i=1}^{k} \hat{B}_i \bmod (2) \tag{11}$$

$$\hat{\mathrm{C}}_{\mathrm{B2}} = [1\cdot \hat{p}_1 + \ldots + k\cdot \hat{p}_k] \bmod (2^b) = \sum_{i=1}^{k} i\cdot \hat{p}_i \bmod (2^b) \tag{12}$$

and based on them, syndromes S_1 and S_2 are formed

$$S_1 = \hat{\mathrm{C}}_{\mathrm{B1}} \oplus \mathrm{C_{B1}} \tag{13}$$

$$S_2 = [\hat{\mathrm{C}}_{\mathrm{B2}} - \mathrm{C_{B2}}] \bmod (2^b) \tag{14}$$

Taken into account that the error control at this code is based on modular arithmetic according to two different modulo, as a final result we get syndromes, whose values will be interpreted in two different ways - syndrome S_1 we will observe from the angle of its Hamming's weight, while the value of syndrome S_2 will always be expressed arithmetically. If we have the case where both of those values are equal to zero, decoder will conclude that the data word is correct, while in other cases it will start with single bit error correction, i.e. multi-bit error detection procedure. In the analysis that follows it will be shown which combinations of those two syndromes indicate the case of single bit errors, and which the situations where double bit error, i.e. burst errors occurs.

A. Single bit error correction

If single bit error occurs, from the form of syndrome S_1 we can easily find its bit position and from the value of S_2, the position of the byte that is affected by it can be instantly determined. Namely, if we take into account that a single bit error always produces a change in value p_i, whereby the arithmetical sum from (8) is increasing or decreasing by i ($1 \leq i \leq k$), from the basic theorems of modular arithmetic the position of byte affected by error is obtained directly from S_2, i.e.:

$$i = S_2, \qquad for \quad S_2 \in (0, k] \tag{15}$$

$$i = 2^b - S_2, \qquad for \quad S_2 \in [2^b - k, 2^b) \tag{16}$$

After calculating the values of the parameter i, error correcting procedure consists in the use of XOR operation on byte that is affected by error, i.e.

$$B_i = S_1 \oplus \hat{B}_i \tag{17}$$

Based on (15), (16) and (17) it can be easily concluded that the procedure of correcting single bit error does not depend on the number of bytes.

B. Double bit error detection

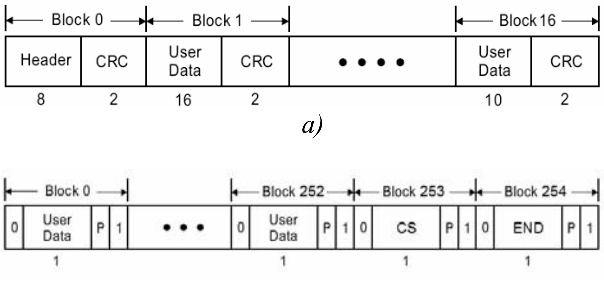
In case of double bit error it is sufficient to analyze two cases. First of them relates to a situation where the double error occurred on different bit positions inside one or two bytes implying a situation where $w(S_1) = 2$ and $S_2 = 0$, i.e. a situation where $w(S_1) = 2$ and $S_2 \neq 0$. In the second case, error can appear on the same bit positions at two different bytes, which means that the values of syndromes will be $w(S_1) = 0$ and $S_2 \neq 0$. This conclusion comes from the fact that for every $i_1, i_2 \in (0, k], i_1 \neq i_2$ inequation $0 < |\pm i_1 \pm i_2| < 2^b$ must be satisfied.

C. Burst error detection

Considering the method used, for detection of burst errors of b length, the value of syndrome S_1 is sufficient. This type of error will be detected in case if it affected one or two adjacent bytes, though in certain situations we can detect burst errors which affect three or more bytes. In order to achieve that, Hamming's weight of S_1 has to be between $2 \leq w(S_1) \leq b$, except in cases when certain forms of burst errors causes situations where $w(S_1) = 1$ and $S_2 = 0$ or $w(S_1) = 0$ and $S_2 > 0$ are possible. Burst errors would be also detected if for $k < 2^{b-1}$ we have $w(S_1) = 1$ and $k < S_2 < 2^b - k$ because in that case the syndrome S_2 would indicate a single bit error on a non-existent byte.

4. PERFORMANCE AND WORKING MODES OF IMH INSTRUMENT

In 1990 the 3 layer EPA model was adopted as the basis for telemetry data transmission in standard IEC 870. One of the early parts of it were Transmission Frame Formats, which included the specification of four frame formats that would be suitable for telecontrol applications - FT1.1, FT1.2, FT2 and FT3 frames. This led to independent development of two electric power-oriented protocols [5] – DNP, which uses FT3 frame format and IEC 60870-5-101, which uses FT1.2 frame format (Fig.3.).



a)

b)

Fig. 3. *Frame formats*: *a) DNP b) IEC 60870-5-101*

However, considering that the IMH instrument sends data (70 KB/s) most frequently through a medium (UTP) which is characterized by a low bit error rate, their integrity check could be done on every 2048 bits and not on every block, as it is the case with those two protocols. This solution does not come only from the characteristic of the medium, but also because of the fact that the proposed SEC-DED-BED code has excellent additional error detection capabilities (Table I), reducing in that way the possibility that an error remains undetected or miscorrected. For example, if we assume that BER $\approx 10^{-5}$ and the data word length is $K = 2048$ bits, the probability that the receiver would perform an erroneous decoding is 1:630000, which is enough to consider the transfer as very reliable. An even more favorable situation is given if we want to check data integrity done on every 128 bits, where under worse conditions (BER $\approx 10^{-4}$) the probability of erroneous decoding amounts to approximately 1:2930000. However, given the fact that the proposed SEC-DED-BED code has the ability to perform single bit correction, its main advantage compared to the CRC is reflected in the significant reduction of the number of requests for retransmission of erroneous received packets. If we have in mind the conditions mentioned above, i.e. when BER $\approx 10^{-5}$ and $K = 2048$ bits, using a 16-bit CRC a request for retransmission will happen on average on each 50-th received packet, while the use of (2070, 2048) SEC-BED-ded code would lead to the same occurrence after 4870 received packets. In another case, when BER $\approx 10^{-4}$ and $K = 128$ bits, this ratio is even more advantageous in favor of the proposed code – the use of 16-bit CRC will require retransmission for every 80-th, while on the other side the use of the (144, 128) SEC-DED-BED code would reduce it to one request for every 12460-th received packet.

On the other hand, if the data transfer happens through the medium that is characterized by a very low bit error rate (optical fiber), the advantage of using the proposed code gets even greater significance. Namely, for many years intensive research are done for a code that would provide reliable transfer of large amounts of data, where the main emphasis was put on the 32-bit CRC. It is known that the 32-bit CRC has great error detection possibilities, but its final performances have never been precisely determined. In a general analysis Koopman [6] showed that the error detection capabilities of 32-bit CRC decrease with increasing number of bits, giving the example that the most famous IEEE 802.3 CRC polynomial has only double bit error detection possibility for data words longer than 91607 bits.

Unlike the CRC, in the case of proposed code, data bit length does not play such an important role, because for fixed b, the proposed code always has SEC-DED-BED characteristics. In practical terms, this means that for $b = 16$ it is possible to transfer up to 524288 data bits, i.e. that with two 280K bit packets all data generated by IMH instrument (70 KB/s) could be transfered.

Having in mind all those characteristics of the proposed code we can easily conclude that the IMH instrument can be extremely well adapted to conditions within communication channel, even during the data transfer (when the receiver sends the request for retransmission). Therefore, the IMH instrument can work in one of three general modes:

1) high noise level mode ($10^{-3} < \text{BER} < 10^{-5}$), where the packet length is 144 bits

2) low noise level mode ($10^{-5} < \text{BER} < 10^{-7}$), where the packet length is 2070 bits

3) very low noise level mode ($10^{-7} < \text{BER} < 10^{-12}$), where the packet length is 280032 bits

Table 1. shows additional error detection capabilities of the proposed code for mentioned packet lengths. From it we can easily notice that the proposed code offers much higher level of data integrity compared to [7], [8].

Table 1. *Error detection capabilities of the proposed code for typical packet lengths*

Packet length (data word + redundancy)	b	Triple-bit errors	Byte plus bit errors	Double byte errors
K = (128 + 16) bits	8	78.24 %	97.25 %	96.67 %
K = (2048 + 32) bits	8	88.11 %	99.98 %	99.98 %
K = (280000 + 32) bits	16	82.03 %	99.98 %	99.98 %

5. CONCLUSION

Detecting potentially dangerous situations and fast mechanism of notification represent some of the main challenges in terms of reliability of the electric power system. In this paper the communication subsystem of the integrated instrument for harmonics measurement (IMH) is presented. In contrast to devices of the similar purpose, the advantage of the IMH instrument is also seen in the use of a new class of SEC-DED-BED codes which allow efficient adaptation to the conditions within a communication channel. This is best seen in the fact that the packet length can vary from 128 up to 524288 bits, which represents a very important improvement compared to existing electric power-oriented protocols. In addition to that, the proposed code offers a high level of protection with the possibility of single bit error correction that CRC has not. This feature can reduce the number of requests for retransmission, which enables a fast information transfer from the IMH instrument to the central computer.

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