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Development of Embedded Power System Data Management System

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Abstract

The power system operation involves regular monitoring of various parameters including voltage, current, system frequency etc. at regular intervals. This huge volume of data storage and transfer is a challenging task, particularly when lower level microcomputers are employed as field devices. The increased computational burden of entropy based compression algorithms and requirement of the probability distribution of symbols makes it difficult to implement for data acquisition. Differential Binary Encoded Algorithm (DBEA) gives a high compression ratio with repetitive, slow varying data array. But it is not suitable for the GSM communication scheme where printable character transmission is possible. An improved algorithm, Modified DBEA (M-DBEA) is developed which not only extends the range of DBEA but also gives a character string containing printable characters only. The results obtained by M-DBEA with practical data values are encouraging and thus implemented at the microcontroller level to develop a handshaking based compressed temperature data transfer system using Arduino UNO microcontrollers. When suitable sensors are used, it is possible to extend the work to develop a smart data management system for compressing real time parameter values collected over the finite time duration and transmit the compressed information through any suitable wired or wireless communication scheme.

Key words

Modified Differential Binary Encoding Algorithm (M-DBEA), Data Array, Compression,

Power System Operation, Embedded System.

1. Introduction

Stable power system operation involves large volumes of data, including parameter monitoring and scheduling information for generation control of individual plants. Either of the data can be considered as a large array with the individual elements being the parameter monitoring value or generation / load demand at some particular time instants. If the volume of data can be reduced by suitable compression algorithm, management of this bulk information will be easier. DBEA was developed to compress unit commitment data to a character string [1]. But the algorithm may fail for some array where the difference between two consecutive elements exceeds beyond 63. The output character string obtained by DBEA can have any ASCII character. But GSM communication support transfer of all printable ASCII characters with ASCII values varying between 32 and 126. This results in the development of a modified approach M-DBEA, for compressing these repetitive data arrays. Reduced computation is extremely important for embedding any compression algorithm at microcontroller level. Conventional entropy based lossless compression schemes like Huffman or Basic Arithmetic Coding involves increased computation and the achievable compression ratio is moderate to low. M-DBEA is implemented at Arduino level and is tested with sample data array to determine the effectiveness of the algorithm at embedded level.

DBEA was not the first approach for compressing data array related to power system applications. In [2], conventional lossless compression techniques were employed to compress power system data and compression ratio of about 10 is achieved. Four lossless compression algorithms based on Arithmetic Coding were developed in [3] and a variable compression ratio above 15 was achieved with various power system operation data of Southern Regional Load Dispatch Centre (SRLDC). A lossless compression technique, RLDA [4] was introduced to compress load profile data for smart metering in smart grid and average compression ratio of 40 is achieved by it. An alternate lossy compression algorithm, FLDC was developed in [5] to compress load profile data based on the identification of load feature where the compression ratio of about 56 can be achieved. As no loss of information is desirable, lossless algorithms are preferable. RLDA comprises of variable length coding followed by entropy coding to reduce the volume of data and thereby have increased computational burden. Conventional lossless algorithms might have lower algorithmic complexity than RLDA but again the floating point arithmetic, probability distribution table formation etc. are the stopping condition for those algorithms. DBEA in contrast comprises of logical comparisons, addition and subtraction of decimal numbers and basic string operations. In order to increase the domain of application of DBEA and to make it make it more suitable for all existing communication schemes, M-DBEA is developed. This paper focus on the comparative analysis of DBEA and M-DBEA for various available unit commitment and parameter monitoring data and successful implementation of M-DBEA in Arduino UNO boards. Online testing of algorithm with necessary handshaking is also successful by using serial communication.

There are several works on implementation of suitable compression algorithm at embedded level in various applications. In [6], an algorithm is developed for compressing power system data in smart grid communication with compression ratio varying between 12.5 and 14.5. This algorithm can be easily implemented in FPGA. A DSP based processor is used to develop a prototype smart meter in [7] which can communicate through ZigBee which is a low-power, low-bit-rate sensor network protocol. The range of compression ratio varies according to SNR and the nature is different for different type of supply voltage waveforms. In [8], small separated dictionary and variable mask numbers were used with the Bit-Mask algorithm to reduce the codeword length of high frequency instructions and a novel dictionary selection algorithm is proposed to increase the instruction match rates. Compression ratio varies within the range of 56% - 76% for benchmarks on ARM Cortex-A9 processor. But for C62×× and C64×× processor, this variation is 61%- 77% and 65% to 83% respectively. Design of a low power 3-lead ECG on-chip with integrated real-time QRS detection and lossless data compression for wearable wireless ECG sensors is discussed in [9] which can achieve an average compression ratio of 2.15 times with standard test data. An ECG signal acquisition system followed by a DSP unit containing ECG compression algorithm is developed in [10], where compression ratio of about 6.86 is achieved. In [11], a highly integrated VLSI implementation of a mixed bio-signal lossless data compressor is developed which is capable of handling multichannel ECG, EEG and DOT. The average compression ratio of about 2 can be achieved by the data compressor present in this portable, wireless brain-heart monitoring system.

In [12], a software based ECG data compression algorithm (LLEDCCE) is proposed where the ECG data array is compressed to character string and the achievable compression ratio is 7.18. The character string obtained from LLEDCCE can be transmitted through GSM and decoded at the receiver end to obtain the actual ECG data values [13]. Another similar software based ECG data compression algorithm, EDCCE is proposed in [14] where the compression ratio increases to 15.72. The combination of lossy and lossless compression algorithm (L2CRQ and LCNRQ respectively) will compress an ECG data array in [15] to form a character string and send the information through GSM communication. At the receiving end, the character string is decoded to obtain the actual ECG data array. The compression ratio achieved by this algorithm is 22.47. Similar to the works discussed [12-15], M-DBEA can compress a repetitive data array to a character string comprising of printable characters. M-DBEA was developed initially in the C-environment and tested with the available scheduling information to determine the effectiveness of the algorithm in terms of compression ratio. Then the algorithm is implemented Arduino level and offline testing is done. Finally, the work is then extended to online testing between two Arduino boards connected serially. The scheduling or parameter monitoring data array is fed to the transmitter board which transmit the compressed encrypted string through TX pin after necessary handshaking. The receiver board receives the encrypted string by RX pin after handshaking and decodes it. The decoded array is displayed in the computer screen connected to the receiver board through the virtual serial port. The block diagram of the proposed system is given in Figure 1. Though the online testing present system does not involve any sensor for monitoring, it is possible to include suitable sensing mechanisms and serial communication can be replaced with other wired or wireless communication.

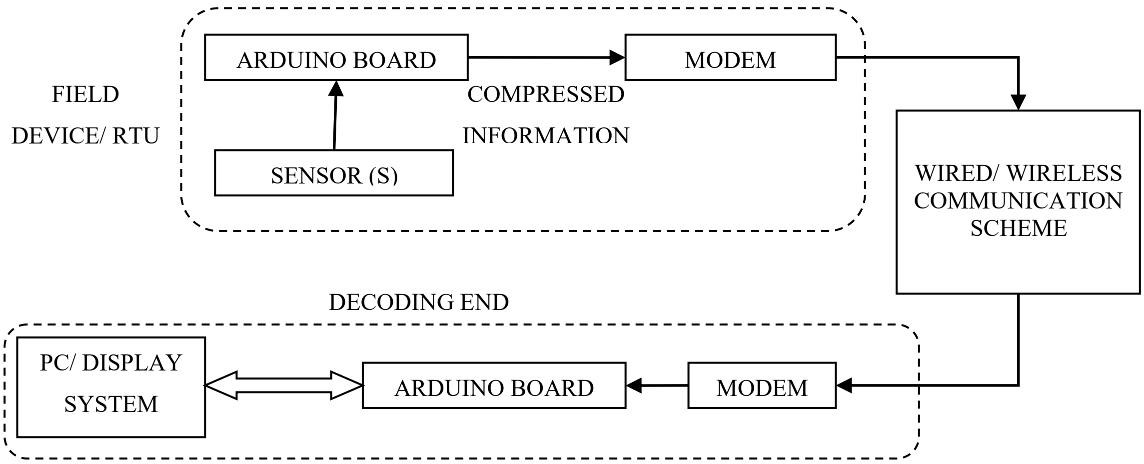


Fig. 1. Block diagram of proposed system

2. Availability Based Tariff (ABT) and Scheduling in Modern Power System

Power System operation is managed by a series of Load Despatch Centre (LDC) at different levels i.e. national, regional and state level. The main objectives of LDCs include matching power demand with system integrity, reliability and security of generation and transmission facilities, system frequency regulation, optimum resource utilization and quick restoration of the system after severe disturbances [16-18]. As electricity can’t be stored, proper matching between power generation and load demand is extremely important. This is possible by accurate load forecasting and preparation of the generation schedule according to that information. Any slight mismatch between load demand and generation will result in the variation of system frequency which is highly desirable in the modern world. In India, the frequency variation is bottlenecked within 48.5- 51.5 Hz by new regulation. But due to the implementation of Availability Based Tariff (ABT), system frequency is normally maintained within 49.5Hz and 50.2 Hz. This also reduces the possibility of inaccurate load forecasting by the generating stations or distribution companies as there is a provision of penalty and/ or reward depending upon the system frequency. ABT can be considered as a 3-part tariff involving fixed charge, energy charge and unscheduled interchange (UI) charge [17, 19].

The capacity or fixed chart of a plant is computed after considering the interest on the loan and working capital, depreciation of the equipments, return on equity and operational expenses including insurance and maintenance. Energy charge includes the fuel cost of the energy fed to the buses which is lower than that being generated as the remaining energy is used to run plant auxiliaries. Both generating stations and distribution companies prepare their schedule in advance for different time blocks and submit the information to the corresponding LDC. If due to some faulty calculation of load forecasting or tripping of one or multiple alternators, there might have some over-drawal or under-drawal thereby violating the schedule. Unscheduled interchange in a particular time block can be defined as the difference between total actual generation and total scheduled generation for a generating station or a seller and the difference between total actual drawal and total scheduled drawal for a beneficiary or a buyer. The penalty or reward for this unscheduled interchange is termed as unscheduled interchange charge and is based on the average frequency of the time block [17, 19]. It implies that when grid frequency is higher than rated value, a GS will be penalized if it generates more than the scheduled value and is rewarded when it is under-generating. Though in either case scheduling is violated, effect will be opposite. Under low frequency condition, it is opposite i.e. lower generating plants are penalized and higher generating units are rewarded.

As load demand in power system varies slightly with time, a day is sub-divided in 96 time blocks each of 15 minutes duration. Load demand is forecasted for all these time blocks by the distribution companies based on which the generation is anticipated for the generating units by LDC. There are two possible types of generating stations namely state owned generating stations for delivering power mostly to the state and central owned inter-state generating station (ISGS) having shares of multiple states. All the state owned generating stations are scheduled by SLDC. But the scheduling of ISGS will be done by RLDC after obtaining the requirement of all the SLDCs operating beneath it. The scheduling process initiates after ISGS informs the concerned RLDC regarding its next day forecasted availability in MW for the next day during 00:00 to

24:00 hours. RLDC informs the SLDC regarding to the next day availability of ISGS and power allotted by if for the state. In the meantime SLDC seeks the next day availability the state owned generating stations and expected load requirement of the distribution company(s) beneath it. After obtaining all these information SLDC prepare the generation schedule for all the generating stations including ISGSs and send the drawal schedule to RLDC by 15:00 hours. By 18:00 hours, RLDC will convey the despatch schedule to each ISGS and net drawal schedule to each beneficiary for all 96 time blocks. If any modification of the generation or drawal schedule is required, it must be informed to RLDC by 22:00 hours so as to incorporate the changes in the schedule. The final schedule is circulated among all ISGS and SLDC at 22:00 hours. This information is then conveyed to state generating stations and distribution company(s) [17].

Any deviation from the allotted generation or drawal schedule at one or multiple time block, results in the UI charges decided by grid frequency at that particular time block (s). In case of any accidental problem or failure in generation or distribution, it is obvious that there will be the necessary deviation from the scheduled value. Under that circumstances, the revised generation or drawal must be informed to the concerned LDC so as to prepare a new revised scheduling chart which will be applicable after 4 time blocks and the generating stations/ distribution company(s) have to bear the UI charges during the entire time duration. So, there might have several revisions of scheduling information and is conveyed to the generating stations and distribution company(s). The final generation or drawal schedule obtained at the end of day is preserved for calculating the UI charges for the respective authority. The structure of the scheduling charts for generating stations and distribution company(s) are different. For distribution company(s), the drawal schedule comprises of the amount of power export and import from (or to) other distribution company or power traders, allocated schedule by the LDC and actual drawal by the company(s) for all 96 time blocks. But for generating stations, the generation schedule comprises of notional availability (possible generation when favourable condition is met), actual availability (generation possible in the present circumstances) and scheduled generation for all 96 time blocks. The ramp-up or ramp-down rate of the alternator in (MW/hr), minimum generation of the alternator and ratio of minimum and maximum generation level must be considered during the preparation of the generation schedule of any generating station [17, 19].

3. Existing Communication Schemes for Power System Operation

The modes of data transfer between LDCs present at various levels can be Power Line Communication, Microwave or Optical Fibre. In Power Line Carrier Communication (PLCC), power line acts as a channel where power frequency waves (conventional 50 Hz supply) and high frequency communication waves exist simultaneously to transfer power as well as data from one place to another. It is already under operation for voice and data transfer through high voltage power line between substations (or LDCs) and was extremely popular till the last decade. But due to the limitations of PLCC, other communication techniques are replacing it and exist only in some circuits only. The limitations are as follows:

a. Competing standards
b. Booster is required for long distance data transfer
c. Data security is not strong
d. Possibility of interference with short wave radio signals
e. Limited rate of data transfer

Microwave communication is the transfer of information by employing EM waves with wavelengths varying from 30cm to 0.1cm and frequencies varying from 1GHz to 300GHz. It is widely used for point-to point communication as due to their smaller wavelengths, convenient type antennas direct them in narrow beams in the direction of receiving antenna. This feature enables nearby microwave equipment to use same frequency without any interference. Due to high frequency of microwaves, the bandwidth is very high i.e. large information can be conveyed through it at any time instant. But due to the line of sight propagation, it can't pass through hills or mountains thereby limiting the use of this communication technology. This results the application of optical fibres for power system data communication.

The optical fibre communication is flexible and a number of fibres can be bundled as cables. In each fibre there might have multiple independent channels each using different wavelength of light by using wavelength division multiplexing (WDM). For long distance data transmission, optical fibre is a good choice as light attenuates a little while passing through the fibre and only a few repeaters are required to cover a large distance. The rate of data transmission in optical fibre is in the range of tens to hundreds GHz/s. As the optical fibre can be bent in any direction and have high speed data transmission, it overcomes the problems involved with microwave communication significantly. The modern trend is to connect all the substations, LDCs and generating station with optical fibre network. Conventionally the scheduling information is transferred between the LDC(s) and generating station(s) by using internet and/or telephonic conversation and thereby requiring human supervision. Similarly, system monitoring data is transferred either by using PLCC, microwave or optical fibre connection, whatever available.

It the volume of data can be compressed by suitable lossy or lossless compression schemes, management of such enormous volume of information will be easier. It is also a known fact that, reduced volume of information results lower energy requirement for transmitting the information and lower memory requirement to store the data. Compression reduces the volume of data significantly and thereby plays an important role in data management. It implies that data management at embedded level is possible by embedding suitable compression algorithm at hardware level. The advantage DBEA was its simplicity which is modified to develop M-DBEA whose output will be an encrypted string comprising of printable characters only. After successful embedding of M-DBEA at Arduino level, it is possible to develop an embedded power system data management system. As M-DBEA can support any suitable communication scheme, the existing technologies can be employed for data transfer. It is also possible to develop an internet based compressed data transfer by using suitable Ethernet shield. This can lead to the application of IOT in power system applications.

4. M-DBEA Compression Scheme

The approach employed in M-DBEA is similar to that of DBEA except binary encoding section. Initially differential coding is performed on the scheduling array (Step A) which is followed by zero count replacement (Step B). An alternative binary encoding approach is followed in M-DBEA (Step C) which is followed by the formation of ASCII value array (Step D) and hence the encrypted character string is formed (Step E). The steps involved in M-DBEA are as given in Figure 2. For decoding the encrypted character string, the reverse process (E-A) followed at the decoding end. If DBEA and M-DBEA is compared for the given example, it is obvious that the number of characters in the output string is 10 for M-DBEA which is much higher than that obtained by DBEA (6 for this case). This clearly indicates that lower compression ratio achieved by M-DBEA in comparison to DBEA. But M-DBEA can handle data array with larger differential values in comparison to DBEA thereby making it effective for all possible power system operational data values.

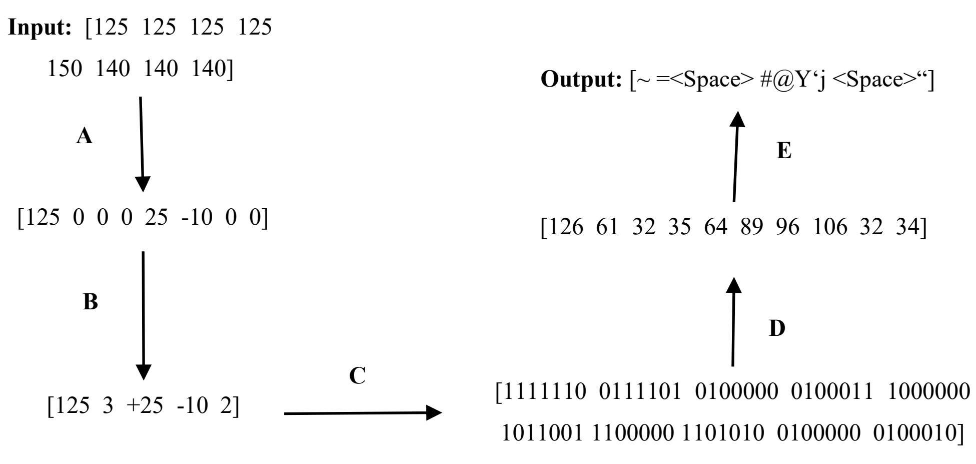


Fig. 2. M-DBEA approach of reducing large data array

The modified array output as obtained after zero count replacement can have four possible types of elements namely first element, zero count, positive and negative difference values. The total numbers of positive or negative difference values in any data array is abbreviated as the total number of changes in the data array. As discussed, the binary coding approach followed in M-DBEA will be different for different types of elements. This encoding is actually responsible for upgrading DBEA so that the encrypted string contains printable characters only. M-DBEA also increases the range of difference values so that any practical scheduling or monitoring array can be compressed. The set of encoding rules for different categories of elements are as given below:

a. The first element of the array should vary between 0 and 4095 and is converted to 12-bit binary array. This array is then divided in two 6-bit binary arrays. If the decimal equivalent of 6-bit binary varies between 32 and 62, 7^{th} bit of the binary array is reset to 0. Otherwise 7^{th} bit is set to 1 and the six bits are complemented.
b. M-DBEA can deal with larger number of zero count which can be as high as 1023. It is converted to 10-bit binary array which is then divided in two 5-bit binary arrays. The identity bits, '01' are added before each of them to form two 7-bit binary arrays.
c. The negative difference of the array can vary between 0 and 255. The magnitude is converted to 8-bit binary equivalent array when then converted to two 4-bit binary arrays. The identity bits, '110' are added before each array to make it a 7-bit binary.
d. In M-DBEA, positive difference value must vary within the range of 0-1023. It thus can be converted to 10-bit binary array which again divided in two 5-bit binary arrays. The identity bits '10' are then added before both the arrays to form a 7-bit binary array.

Tab. 1. Comparison of binary encoding performed in DBEA and M-DBEA

Sl. No.	Type of element	Range of values		No. of binary bits	
		DBEA	M-DBEA	DBEA	M-DBEA
1	First element	0-65535	0-4095	16	14
2	Zero count	0-127	0-1023	8	14
3	Magnitude of positive quantity	0-63	0-255	8	14
4	Magnitude of negative quantity	0-63	0-1023	8	14

After performing the binary encoding, the ASCII value equivalent array is obtained with elements varying within 32 to 126. The characters present in the encrypted character string are the characters corresponding to the content of ASCII value equivalent array. Comparative analysis of the binary encoding section of DBEA and M-DBEA is given in Table 1. It clearly indicates that M-DBEA can handle differential values over a wide range and thereby suitable for any practical data array associated with Power System operation. Though the range of first element is lower in M-DBEA, it is not a matter of concern as unit commitment or parameter monitoring data generally will exceed this value.

5. Results and Analysis

Compression ratio is an important factor to determine the effectiveness of any compression algorithm. Huffman Coding based approach developed in MATLAB to compress any large data array associated with power system [20] gives a much lower compression ratio in comparison to the other available works. This problem is overcome by DBEA [1] and extremely high compression ratio was achieved for majority of the available data. While implementing M-DBEA, the number of characters in the encrypted string is equal to the number of elements in the ASCII value equivalent array. This in turn related with the total number of changes in the elements of scheduling array. It implies that similar to DBEA, higher will be the number of changes in the scheduling array, larger will be the encrypted string length and lesser will be the compression ratio. A survey of available scheduling information clearly indicates that the number of changes in any scheduling array rarely exceeds 15. DBEA and M-DBEA developed in C-environment and tested with various scheduling information of Santaldih Thermal Power Station (STPS). The comparative analysis of the results being obtained is given in Table 2 which clearly indicates that though the compression ratio obtained by M-DBEA is lower than DBEA, the algorithm is suitable for all the available data. The variation of compression ratio obtained with DBEA and M-DBEA for different number of changes is given in Figure 3.

Tab. 2. Variations CR obtained by DBEA and M-DBEA for unit commitment data of STPS

Sl. No.	Date	No. of changes	CR for DBEA	CR for M-DBEA
1	24/03/15	0	96	72
2	02/04/15	16	12.52	6.26
3	25/04/15	8	-	12
4	20/05/15	13	15.16	7.58
5	28/05/15	6	19.2	16
6	02/06/15	0	96	72

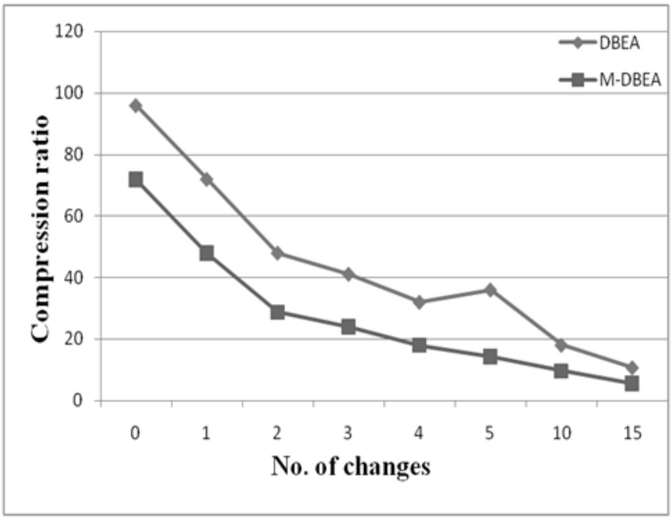


Fig. 3. Comparison between DBEA and M-DBEA while compressing scheduling array with varying number of changes

It is obvious that parameter monitoring data is of much higher volume in comparison to generation scheduling data. The hourly data related with power transferred over a 400kV line at different time intervals are compressed by DBEA and M-DBEA. The comparative analysis of results being obtained is given in Table 3. The table clearly indicates that DBEA can be applied to such data set effectively and a high compression ratio is achieved. The average compression ratio obtained by DBEA and M-DBEA over the entire day is 32.7 and 16.8 respectively. It is due to the fact that, power transferred over the line will vary frequently and thereby having larger number of elements in the modified array. Frequency parameter monitoring data will have reduced variation and thus higher compression ratio can be achieved with such data.

Tab. 3. CR obtained by DBEA and M-DBEA for power transfer data a 400kV line

Sl. No.	Time	CR for DBEA	CR for M-DBEA
1	01-02	28.24	14.69
2	02-03	35.12	18.46
3	03-04	38.92	21.82
4	04-05	35.12	18.95
5	05-06	46.45	24.83
6	06-07	22.15	11.43
7	07-08	32	17.14
8	06-09	27.17	14.12

9	09-10	14.74	7.53
10	10-11	34.29	17.7
11	11-12	28.05	14.4
12	12-13	18.78	9.56
13	13-14	35.41	17.7
14	14-15	48	23.48
15	15-16	45.96	22.5
16	16-17	26.02	13.33
17	17-18	11.43	5.78
18	18-19	27.34	14.03
19	19-20	65.45	32.73
20	20-21	20.97	10.69
21	21-22	31.3	16.12
22	22-23	69.68	33.75
23	23-00	9.6283	4.85
24	00-01	24.83	12.93

6. System Realization

The results being obtained clearly indicate the effectiveness of M-DBEA for compressing both generation scheduling and parameter monitoring data. Simplicity of the algorithm and possibility of encountering repetitive data for power system operation encourages its implementation at embedded level. This algorithm is developed and tested in real time with handshaking, between two Arduino UNO microcontrollers connected serially by cross linked wires. The arrangement is given in Figure 4.

A sample data array, [225, 225, 225, 225, 275, 310, 310, 310, 310, 300] is uploaded in the encoding end board which compress it to an encrypted character string and transmit it through TX pin when it receives the handshaking character ‘R’ in response to the continuous transmission of character ‘S’ from the encoding board. At the decoding end, handshaking is followed by the reception the character string which is then decoded to obtain the sample data array. The result obtained from the virtual serial monitor of the Arduino at encoding and decoding end is given in Figure 5 (a) and 5 (b) respectively.

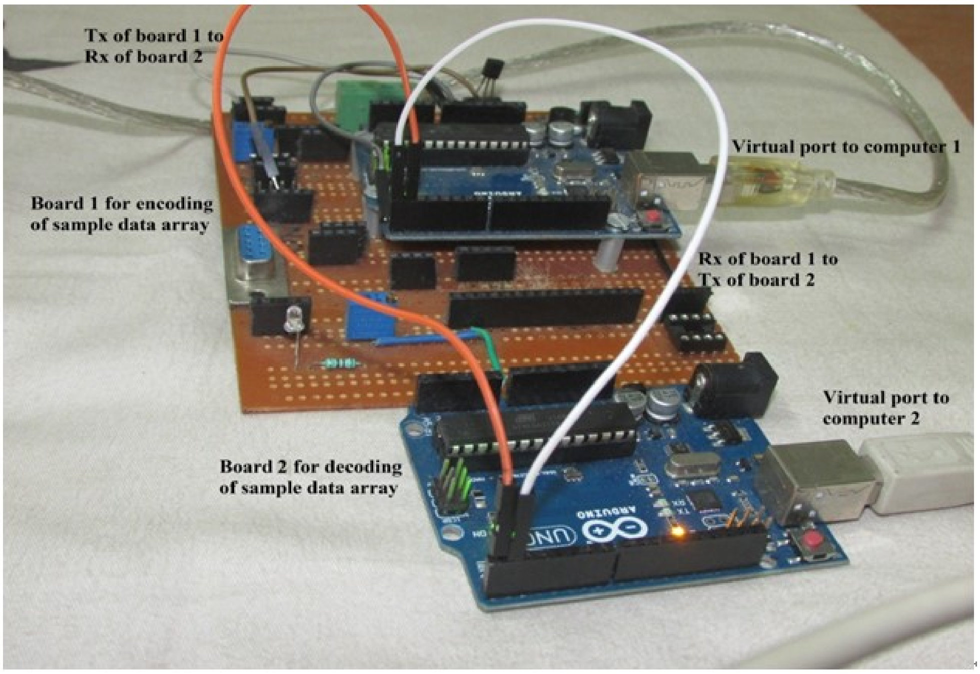


Fig. 4. Experimental set-up of testing M-DBEA between two Arduino UNO boards

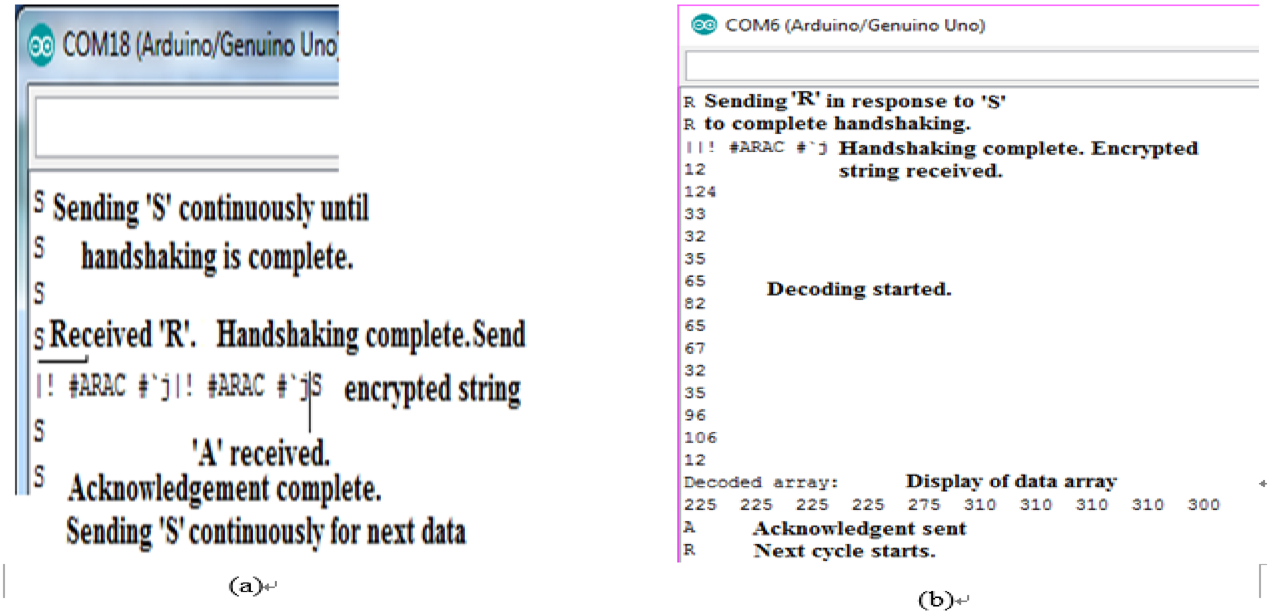
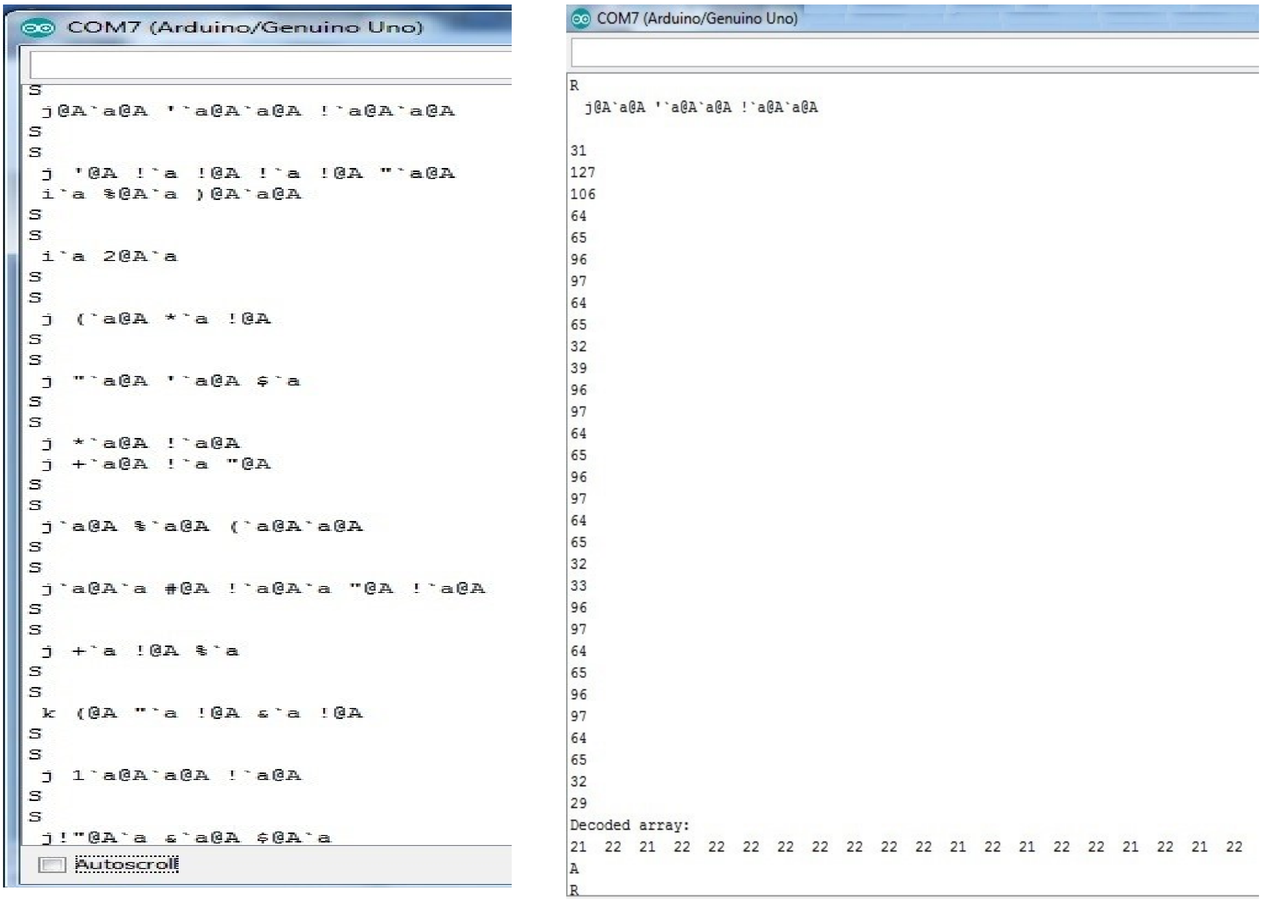


Fig. 5. Display of result in virtual serial monitor (a) At encoding end; and (b) At decoding end

The system is also realized by introducing a LM35 temperature sensor at the encoding end to measure temperature each second and compressing the temperature values collected over a finite time interval (20 seconds in this case). This compressed information is transmitted serially to the decoding end where the actual data is extracted and is displayed in the computer string. The result obtained from the virtual serial monitor of the Arduino at encoding and decoding end for measuring temperature values is given in Figure 6 (a) and 6 (b) respectively. For power system applications, LM35 will be replaced by corresponding sensors and suitable modems will be interfaced with the Arduino board. Then any wired or wireless communication scheme can be employed to transfer data between two boards. At the decoding end, Arduino can be interfaced with PC where data values collected by field devices can be displayed and stored for future references.



(a) (b)

Fig. 6. Compressed temperature monitoring system result in virtual serial monitor (a) At encoding end; and (b) At decoding end

7. Conclusion

As very few works are available in compressing power system operation data, this embedded M-DBEA algorithm will open a new trend in power system operation. The embedded hardware can communicate with other embedded systems to transfer various power system operational data between LDC and generating station through suitable communication channel. There are few lossy and lossless algorithms for compressing any ECG data array to a character string. The comparison M-DBEA with the existing lossless algorithms in terms of compression ratio is given in Table 4. Previous discussions clearly indicate that for majority of the available data array, the compression ratio is well above 10 and thereby showing improved result than LLEDCCE and EDCCE for majority of data. The complexity of M-DBEA is much lower in comparison to LLEDCCE and EDCCE. Furthermore, none of the works are implemented at embedded system level and thereby making M-DBEA slightly advantageous over the existing works.

Tab. 4. Comparison of the performance of M-DBEA and other similar lossless algorithms

Algorithm	LLEDCCE [12]	EDCCE [14]	DBEA [1]	M-DBEA
CR	7.18	15.72	6.5- 96	3.6-72

Though the algorithm was illustrated with a sample data array, it is obvious that the algorithm will work with various scheduling or monitoring data array. The algorithm was tested successfully with a sample scheduling array available in [21] and the encoded data array is obtained at the decoding end. The wired communication medium can be replaced by suitable wireless techniques like IR, RF, GSM etc. The work can be extended to develop a smart data acquisition system sending the compressed information collected during a finite time interval to the control room using suitable wireless communication scheme for further processing. The block diagram of such system is given in Figure 7. During the formation of smart grid, data management is extremely important which can also be done by employing suitable data compression techniques. For compressing large data array of repetitive nature, M-DBEA is a good choice due to its simplicity and lower execution time.

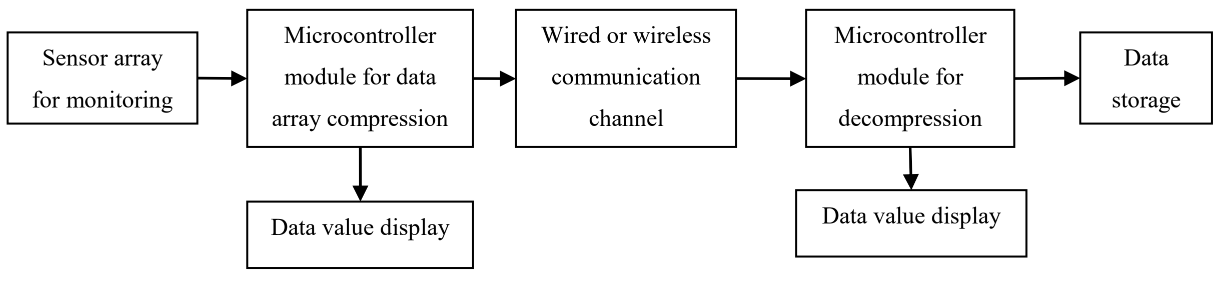


Fig. 3. Block diagram of compressed Data Acquisition System (DAS)

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References

1. Subhra J. Sarkar, Palash K. Kundu, Gautam Sarkar DBEA: A Novel Approach of Repetitive Data Array for Power System Application, 2017, Int. Conf. of Convergence of Technology (I2CT 2017), 2017, Pune, India, April 2017, pp. 824-827.
2. Sarasij Das, 'Power System Data Compression for Archiving', M.S. Thesis, Faculty of Engineering, Indian Institute of Science, 2007.
3. Sarasij Das, P S Nagendra Rao, Arithmetic coding based lossless compression schemes for power system steady state operational data, 2012, Electrical Power and Energy Systems, Vol. 43, No. 1, December 2012, pp. 47- 53.
4. Andreas Unterweger, Dominik Engel, Resumable Load Data Compression in Smart Grids, 2015, IEEE Trans. on Smart Grid, Vol. 6, Issue 2, March 2015, pp. 919-929.
5. Xing Tong, Chongqing Kang, Qing Xia, Smart Metering Load Data Compression Based on Load Feature Identification, 2016, IEEE Trans. on Smart Grid, Vol. 7, No. 5, September 2016, pp. 2414- 2422.
6. Jesmin Khan, Sharif Bhuiyan, Gregory Murphy, Johnathan Williams, Data Denoising and Compression for Smart Grid Communication, 2016, IEEE Trans. on Signal and Information Processing over Networks, Vol. 2, No. 2, June 2016, pp. 200-214.
7. Norman C. F. Tse, JohnY.C. Chan,Wing-Hong Lau,Jone T. Y. Poon, L. L. Lai, Real-Time Power-Quality Monitoring With Hybrid Sinusoidal and Lifting Wavelet Compression Algorithm, 2012, IEEE Trans. on Power Delivery, Vol. 27, No. 4, October 2012, pp. 1718-1726.
8. Wei Jhih Wang, Chang Hong Lin, Code Compression for Embedded Systems Using Separated Dictionaries, 2016, IEEE Trans. on Very Large Scale Integration (VLSI) Systems, Vol. 24, No. 1, January 2016, pp. 266-275.
9. Chacko John Deepu, Xiaoyang Zhang, Chun Huat Heng, Yong Lian, A 3-Lead ECG-on-Chip with QRS Detection and Lossless Compression for Wireless Sensors, 2016, IEEE Trans. on Circuits and Systems—II: Express Briefs, Vol. 63, No. 12, December 2016, pp. 1151-1155.
10. Ching-Hsing Luo, Wei-Jhe Ma, Wen-Ho Juang, Shin-Hung Kuo, Chih-Yuan Chen, Pei-Chen Tai, Shin-Chi Lai, An ECG Acquisition System Prototype Design with Flexible PDMS Dry

Electrodes and Variable Transform Length DCT-IV Based Compression Algorithm, 2016, IEEE Sensors Journal, Vol. 16, No. 23, December, 2016, pp. 8244- 8254.

11. Ericson Chua, Wai-Chi Fang, Mixed Bio-Signal Lossless Data Compressor for Portable Brain-Heart Monitoring Systems, 2011, IEEE Trans. on Consumer Electronics, Vol. 57, No. 1, February 2011, pp. 267-273.
12. S.K. Mukhopadhyay, M. Mitra, S. Mitra, A lossless ECG data compression technique using ASCII character encoding, 2011, Computers and Electrical Engineering, Vol. 37, Issue 4, July 2011, pp 486-497.
13. S.K. Mukhopadhyay, S. Ghosh, S. Chakraborty, S. Das, M. Mitra, S. Mitra, Lossless Electrocardiogram Compression Technique and GSM Based Tele-Cardiology Application, 2013, International Journal on Smart Sensing and Intelligent Systems, Vol. 6, No. 3, June 2013, pp 888-909.
14. S.K. Mukhopadhyay, M. Mitra, S. Mitra, An ECG signal compression technique using ASCII character encoding, 2012, Measurement, Vol. 45, Issue 6, July 2012, pp. 1651-1660.
15. S.K. Mukhopadhyay, M. Mitra, S. Mitra, ECG signal compression using ASCII character encoding and transmission via SMS, 2013, Biomedical Signal Processing and Control, Vol. 8, No. 4, July 2013, pp 354- 363.
16. Subhra J. Sarkar, Palash K. Kundu, A Proposed Method of Load Scheduling and Generation Control using GSM and PLCC Technology, 2015, Michael Faraday IET International Summit 2015 (MFIIS 2015), Kolkata, India, September 2015, pp. 273-277.
17. CERC, Indian Electricity Grid Code, 2010, http://www.cercind.gov.in/2010/ORDER /February2010/IEGC_Review_Proposal.pdf, access date March 2016.
18. Statement of reasons, CERC, http://www.cercind.gov.in/2014/regulation/sor96.pdf, access date March 2016.
19. Subhra J. Sarkar, Nabendu Kr. Sarkar, Aritra Banerjee, A Novel Huffman Coding based Approach to Reduce the Size of Large Data Array, 2016, IEEE Int. Conf. on Circuit, Power and Computing Technologies (ICCPCT- 2016), Nagercoil, India, March 2016, pp. 1-5.
20. West Bengal State Load Despatch (WBSLDC) Website, http://wbsldc.in/schd.aspx? typ=5, access date April 2016.