FINITE STATE MACHINES POWER DISSIPATION CLASSIFICATION

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Abstract: Reduction of the power consumption of digital system can be obtained in many ways. Integrated circuits fabricated in CMOS technology consume power when the state of the output of logic element (gate or flip-flop) changes into opposite. Therefore minimizing the number of such changes lead to a reduction of the power consumption. In this paper is presented research of dependence the power dissipation in finite state machines (FSMs) on both probabilities of ones on input lines and probabilities of changes in the input value. The classification scheme for graphs obtained for those dependencies is also proposed. This classification can be used for testing the results of the power reduction process as well as testing the behavior of finite state machine while changing the statistical properties of input signals. Proposed classification can also be used for developing new methods and algorithms of reducing the power dissipation in finite state machines.

Keywords: power dissipation, FSM, power classification

1. Introduction

The problem of reducing the power consumption of digital systems has been an interest of many scientists in the past few years. The special incentive for intensification the research was a huge increase in the popularity of mobile devices (mobile phones, portable computers, including laptops, PDAs and netbooks). It was also important for the global trend to develop energy-efficient, and therefore environment friendly systems. Power reduction can also increase the performance and reliability of the system.

Value of the power dissipated in CMOS digital circuit can be obtained using the following formula [3]

$$P_a = \frac{1}{2} V_{DD}^2 f C_{out} N_a \qquad (1)$$

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where: P_a - is power dissipated by element a; V_{DD} - is the power supply voltage; f - is the operating frequency; C_{out} - is the output capacitance; N_a - is the switching activity (the number of output value transitions is one cycle of f).

According to equation (1) reduction of the power dissipation can be obtained through decreasing value of factors V_{DD}, f, C_{out}, or N_a. But only switching activity can be reduced using algorithmic solutions. Examples of such approach are: using the specific state assignment methods ([2], [5], [9], [12]), decomposition of large circuits [10], using embedded memory blocks (in FPGA) [6]. Review the most known methods of state assignment can be found in [14].

One of the stages of low-power design and power-aware design is to estimate the power consumption of the digital system. Classical techniques for power estimation of finite state machine (FSM) were presented in [3], and [4]. In order to calculate the power consumed by FSM it is necessary to know either the transitions' graph or transitions' table (or list). Additionally the knowledge about the properties of the input sequence is needed. Mainly these properties are probabilities of input vector, which depends on probability of one (or zero) on input line [13].

The aim of the research presented in this paper is to determine the effect of power dissipation depending on the probability of the ones depending on the input and the frequency of changes in the value of the inputs of finite state machine (FSM).

2. Dependence of power on probabilities

2.1 Research methodology

The power value of the FSM is proportional to the switching activity (the frequency of switching the value in output) of the flip-flops carrying a memory function. Switching activity estimation process consists of three steps [7]:

- calculate the static probabilities of each state of the finite state machine (FSM) using the Chapman-Kolmogorov equations; static probability is a probability that the FSM is in a particular state at time t;
- calculate the transition probabilities ie. probabilities that FSM changes its state from one state to another;
- calculate the switching activity of flip-flops.

Based on the calculated flip-flop switching activity can be calculated power dissipated by each flip-flop, then the total power consumed by the system.

Assuming equal probability of ones on all inputs of FSM the dependence of the power dissipation on the probability of ones can be determined. The value of

$P(x_i = 1)$ varies in the range [0, 1], where $P(x_i = 1)$ is a probability that input line x_i is carrying logic one.

For different values of the probability $P(x_i = 1)$ were obtained different values of power dissipation. The following probabilities' values were taken into account: 0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 0.99. The results formed curves that for a variety of FSMs arranged in a characteristic way. When analyzing the generated graphs of power consumption of a FSM the following classification scheme was proposed [8], [11]:

1. Class 1 (Gaussian-like graphs, Figure 1a), which is divided into sub-classes:
   - 1 - symmetric Gaussian distribution graph for which the maximum value falls in the middle of the graph (probability value equal to 0.5);
   - 1L - asymmetric Gaussian distribution graph for which the maximum value falls on the left half of the graph (the probability value of less than 0.5);
   - 1R - asymmetric Gaussian distribution graph for which the maximum value falls on the right half of the graph (for values greater than 0.5 probability).
2. Class 2 (graphs a constant value, Figure 1b): the power value does not depend on the value of probabilities of the ones on the input line.
3. Class 3 (linear graphs, Figure 1c), which is divided into sub-classes:
   - 3R - graph linearly rising;
   - 3F - graph linearly falling;
4. Class 4 (logarithmic graphs, Figure 1d), which is divided into sub-classes:
   - 4R - graph logarithmically rising;
   - 4F - graph logarithmically falling;
5. Class 5 (exponential graphs, Figure 1e), which is divided into sub-classes:
   - 5R - graph exponentially rising;
   - 5F - graph exponentially falling.
6. Class 6 (parabolic graphs, Figure 1f), which is divided into sub-classes:
   - 6 - symmetric parabolic graph for which the minimum value falls in the middle of the graph (probability value equal to 0.5);
   - 6L - asymmetric parabolic graph for which the minimum value falls on the left half of the graph (the probability value of less than 0.5);
   - 6R - asymmetric parabolic graph for which the minimum value falls on the right half of the graph (for values greater than 0.5 probability).

In some cases, the graph cannot be classified exactly in the class due to slight inaccuracies. In such cases, the graph was indicated by the prefix "~", which has formed additional classes: ~1, ~1L, ~1R, ~2, ~3R, ~3F, ~4R, ~4F, ~5R, ~5F, ~6, ~6L, ~6R.

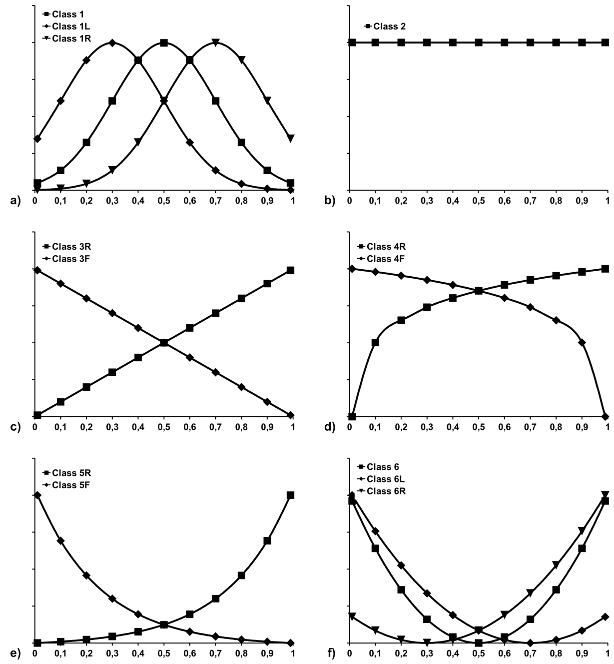

Fig. 1. Graphs for classes 1, 1L, 1R (a), 2 (b), 3R, 3F (c), 4R, 4F (d), 5R, 5F (e), 6, 6L, 6R (f)

3. Experimental results

Table 1 shows the classification of graphs created for standard benchmark circuits [1]. In the column "Benchmark" is placed the name of the benchmark. Column "Class" contains the name of the class to which the graph was assigned, the column "Binary" contains the results for the FSM encoded using binary encoding (the code of the state corresponds to the number of binary encoded number of state), while the column "one-hot" contains the results for the FSM encoded using one-hot encoding (number of state code in a one-hot encoding).

In addition in columns "Binary" and "One-hot" is indicated that the used encodings gave a higher maximum score (using the "+") or whether the results are identical or nearly identical (with "*"). Next columns describe the differences in the classification of the FSM encoded using binary and one-hot encoding. The column "Exact" specifies that in both cases the results are in the same class, while the column "Approximate" indicates that in both cases the results are in the same approximate class (preceded by "~"). The last column "Mixed" contains information about the classification of the mixed power graphs for FSMs encoded using binary encoding and one-hot encoding, the "W" means that both graphs are classified into different subclasses of one class, while "S" - when the graphs fall into two different classes.

Table 2 shows the allocation of power dependence graph of benchmark for each class. The column "Class" indicates the name of the class, while the column "Benchmark" indicates the benchmark name assigned to the class. If the graph is classified only for benchmark which has been encoded with binary code, the name has an extension ".b" added to the end of its name, and when the graph is classified only for benchmark that has been encoded with one-hot code, the name has an extension ".o". For some classes there were no benchmarks assigned, e.g. class 6, class 6L, and class 6R.

For the calculation 51 examples were used, and all of them have been encoded with two codes what in result gave 102 graphs. Most of the graphs were assigned to classes 1, 1L and 1R (57 charts, which gives 56%). In addition, one graph (s27.o) belongs to the class ~1, so that the total number of graphs belonging to different variants of the class 1 is equal to 58 (57%). The four graphs (dk27.o, and both charts dk512.o example tav) belonged to class 2, while five (ex1.b, planet.o, planet11.o, and both graphs of benchmark S510) to the class ~2 (4% and 5% respectively). Class 3R, 4R and 5R was represented by 7 graphs (dk27.b, ex2.o, mark1.b and ex4 and modulo12 at both encoding methods), 4 graphs (dk16, dk17) and 4 graphs (s1488, s1494) respectively, (7% , 4%, and 4%), and the classes 3F, 4F and 5F was represented by 1 graph (ex3.o), 2 graphs (keyb.o, s298.o) and 3 graphs (keyb.b, planet.b, planet11.b) respectively (1%, 2% and 3%). To class ~3R there were assigned 10 charts, 2 graphs belong to the class ~4R, and to the class ~3F - 2 charts. None graphs were assigned to the following classes: 6, 6L, 6R, ~1L, ~1R, ~4F, ~5R, ~5F, ~6, ~6L, ~6R.

In 16 of 51 cases (31%) curves for FSMs encoded with a binary code were assigned for other classes than the same FSMs encoded with one-hot code, wherein in 7 cases there were different subclasses within a single class (beecount, donfile, ex2, lion, lion9, mark1 and S27), and 9 were the different classes (dk27, dk512, ex1, ex3, EX7, keyb, planets, planet11 and s298).

Qualification for more than half the graphs to classes 1, 1L and 1R partially confirms the hypothesis that the graph of the power of the probabilities of ones on the inputs for FSM corresponds to a Gaussian distribution.

Over 30% of the graphs were classified into different classes and subclasses, depending on the encoding method used. Therefore it can be concluded that the encoding of internal states of FSM has a very large impact on the power consumption characteristics. This is particularly evident in the examples ex3 and ex7, which resulted in the classification of the binary encoding to the class ~3R (where the power increases with an increase in the probabilities of ones), while the one-hot encoding

Table 1. Classification of the dependence of power dissipation of the standard benchmarks on probabilities of ones on inputs

Benchmark	Class		Exact	Approximate	Mixed
	Binary	One-hot			
bbara	1R	1R+	+		
bbsse	1R*	1R*	+		
bbtas	1L	1L+	+		
bbtas2a)	1R	1R+	+		
beecount	1	1L+			W
cse	1L	1L+	+		
dk14	1	1	+		
dk15	~3R	~3R+		+	
dk16	4R+	4R	+		
dk17	4R	4R+	+		
dk27	3R	2			S
dk512	~3R	2			S
donfile	1R+	1			W
ex1	~2+	~3R			S
ex2	~3R+	3R			W
ex3	~3R*	3F*			S
ex4	3R	3R+	+		
ex5	~4R*	~4R*		+	
ex6	1R	1R+	+		
ex7	~3R*	~3F*			S
keyb	5F	4F+			S
lion	1	1R+			W
lion9	1L+	1R			W
mark1	3R	~3R+			W
mc	~3R	~3R+		+	
modulo12	3R	3R+	+		
opus	1L	1L+	+		
planet	5F+	~2			S
planet11	5F+	~2			S
pma	1R+	1R	+		
s1	1L+	1L	+		
s1488	5R	5R+	+		
s1494	5R	5R+	+		
s1a	1L+	1L	+		
s208	1	1	+		
s27	1	~1+			W
s298	~3F+	4F			S
s386	1R	1R+	+		
s420	1	1	+		
s510	~2*	~2*		+	
s8	1L	1L+	+		
s820	1L	1L+	+		
s832	1L	1L+	+		
sand	1R+	1R	+		
shiftreg	1	1	+		
sse	1R*	1R*	+		
styr	1R	1R+	+		
tav	2	2	+		
tma	1	1	+		
train11	1L	1L+	+		
train4	1L	1L+	+		

Table 2. Allocation of graphs for benchmarks according to classes

Class	Benchmarks
1	beecount.b, dk14, donfile.o, lion.b, s208, s27.b, s420, shiftreg, tma
1L	bbtas, beecount.o, cse, lion9.b, opus, s1, s1a, s8, s820, s832, train11, train4
1R	bbara, bbsse, bbtas2, donfile.b, ex6, lion.o, lion9.o, pma, s386, sand, sse, styr
2	dk27.o, dk512.o, tav
3R	dk27.b, ex2.o, ex4, mark1.b, modulo12
3F	ex3.o
4R	dk16, dk17
4F	keyb.o, s298.o
5R	s1488, s1494
5F	keyb.b, planet.b, planet11.b
6	
6L	
6R	
1	s27.o
1L	
1R	
2	ex1.b, planet.o, planet11.o, s510
3R	dk15, dk512.b, ex1.o, ex2.b, ex3.b, ex7.b, mark1.o, mc
3F	ex7.o, s298.b
4R	ex5
4F	
5R	
5F	
6	
6L	
6R	

- the class ~3F (where the power decreases with an increase in the probabilities of ones).

Therefore, it is possible to develop a method of encoding the FSM internal states, which would provide the desired characteristics of the power depending on the probabilities of the ones on the input lines.

4. Dependence of power on frequency

Described above dependence do not give a complete picture of the characteristics of the power consumption of a FSM. It is also appropriate to examine the dependence of the FSM power on the input signal change frequency (clock frequency must be greater than the frequency of the input signal changes). Therefore, it is a need to go on the characteristics of the probabilities of ones on inputs to the frequency of changes in the value of the input signal.

4.1 Research methodology

We can assume that the maximum frequency of the signal is obtained by $P(x_i = 1) = 0.5$, which is the equally likely changed from 1 to 0 and vice versa. By increasing $P(x_i = 1)$ from 0,5 to 1, and the reduction from 0,5 to 0 the frequency changes of the signal will be decreased. To calculate the probability of a change of the signal on input it is possible to use the following expression:

$$P(x_i) = 2 \times P(x_i = 0) \times P(x_i = 1) \qquad (2)$$

To create a graph of the dependency of power dissipated in the FSM on probability of changing the input value, it should be noted that for the value of the probability of ones on input lines equal $P(x_i = 1) = p$ and $P(x_i = 1) = 1 - p$ (where $p \in (0; 0.5)$) the frequency of changes of the input signal is the same. Power value is therefore the sum of the power obtained for $P(x_i = 1) = p$ and $P(x_i = 1) = 1 - p$.

In other words, the graph of the dependency of power dissipated in the FSM on the probability of ones on input lines allowed to create new graphs based on the probability of changes in the input signal, by reflection axis $P(x_i = 1) = 0.5$, and adding up the curves obtained. In the resulting graph, the horizontal axis is the frequency of the signal. the discussed process is shown schematically in Figure 2.

Using a similar strategy, as in the previous section there was developed a FSM power graphs classification based on the resulting characteristics:

1. Class LR - the graphs are rising logarithmic curves (Figure 3a).

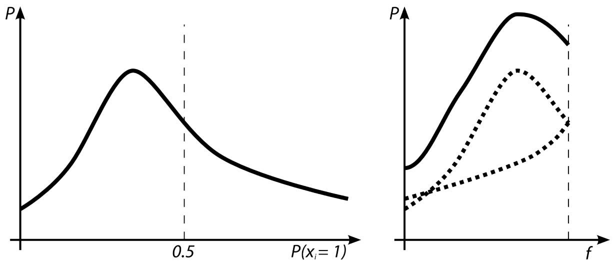

Fig. 2. Creating a graph based on the probability of changes in the input signal from a graph of the dependency of power dissipated in the FSM on the probability of ones on the input lines

2. Class LF - the graphs are falling logarithmic curves (Figure 3b).
3. Class C - the graphs are horizontal lines (Figure 3c).
4. Class IR - the graphs are rising in an irregular manner (Figure 3d).
5. Class IF - charts are falling in an irregular manner (Figure 3e).

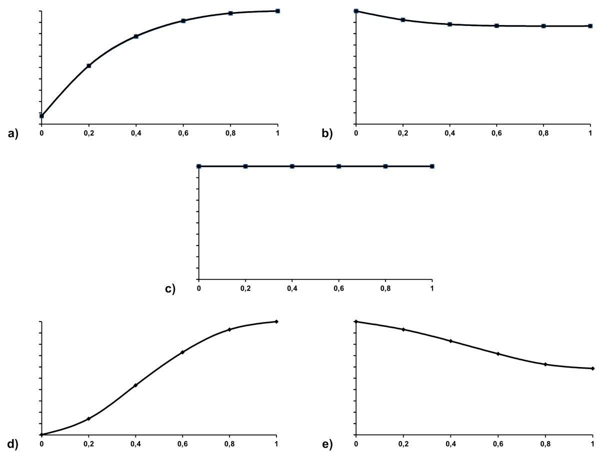

Fig. 3. Graphs for classes LR (a), LF (b), C (c), IR (d), and IF (e)

5. Experimental results

Table 3 shows the classification of the dependency of power dissipated by FSM on the frequency of the input signal changes for standard benchmarks [1]. In the column

"Benchmark" placed the name of the test. Column "Class" contains the name of the class to which a power graph was assigned, the column "Binary" contains the results for the FSM encoded using binary encoding, while the column "one-hot" contains the results for the FSM encoded using one-hot encoding. Next columns define the differences in the classification of the system encoded in binary and one-hot encoding. The column "Exact" specifies that in both cases the results are in the same class, while the column "Approximate" indicates that in both cases the results are in the same approximate class (preceded by "~"). The last column "Mixed" contains information about the mixed dependence graph classification for FSMs encoded using binary and one-hot encoding.

According to Table 3 it can be noticed that the most graphs are qualified to class LR (76 out of 102, giving 74.5%). To class LF there were qualified seven graphs (ex4, keyb.b, mc, planet.b and planet11.b) which gives 6.9%, while to class C - 8 graphs (dk27.o, ex2.o, planet.o, planet11.o and both graphs for modulo12 and tav) which gives 7.8%. To class IR 3 graphs were qualified (cse and keyb.o) which gives 2.9%, while the class IF - 4 graphs (s1488 and s1494) that gives 3.9%. To class C 4 were qualified (3.9%) graphs (dk27.b, dk512.o, mark1.b, s298.b). 7 graphs (13.8%) were classified into two different classes depending on the used encoding (dk512, ex2, keyb, mark1, planets, planet11, s298), and 1 benchmark (dk27) was assigned to the same but approximate class.

Variability in the classification of graphs of power depending on the frequency of the input signal changes to different classes when different methods of encoding FSM internal states were used, says the existence of the large impact of encoding methods to power. This is particularly evident for benchmark "keyb", where using the binary encoding leads to a qualification to Class LF, while using the one-hot encoding - to IR class. Also, in the examples "planet" and "planet11" it is visible the shift from class LF (binary coding) to class C (one-hot encoding). In these examples, the power dissipation is increasing with decreasing the frequency during the transition from the one-hot encoding to the binary encoding.

Some examples are classified to class LF (7 examples, 6.9%), and IF (4 examples, 3.9%), for which the frequency of the input signal changes is increasing while the power consumed by the FSM decreases. At the same time, for some benchmarks encoded using the different methods of encoding (binary and one-hot) the graphs of power consumption on the probability of changing input signals were classified into different classes. This means that it is possible to provide such a method of encoding the internal states of a FSM, which allows to obtain the desired relationship between power (corresponding to a specific class) and a FSM operating frequency (for exam-

Table 3. Classification of the dependence of power dissipation of the standard benchmarks on changes of frequency of input signals

Benchmark	Class		Exact	Approximate	Mixed
	Binary	One-hot			
bbara	LR	LR	+		
bbsse	LR	LR	+		
bbtas	LR	LR	+		
bbtas2a)	LR	LR	+		
beecount	LR	LR	+		
cse	IR	IR	+		
dk14	LR	LR	+		
dk15	LR	LR	+		
dk16	LR	LR	+		
dk17	LR	LR	+		
dk27	~C	C		+	
dk512	LR	~C			+
donfile	LR	LR	+		
ex1	LR	LR	+		
ex2	LR	C			+
ex3	LR	LR	+		
ex4	LF	LF	+		
ex5	LR	LR	+		
ex6	LR	LR	+		
ex7	LR	LR	+		
keyb	LF	IR			+
lion	LR	LR	+		
lion9	LR	LR	+		
mark1	~C	LR			+
mc	LF	LF	+		
modulo12	C	C	+		
opus	LR	LR	+		
planet	LF	C			+
planet11	LF	C			+
pma	LR	LR	+		
s1	LR	LR	+		
s1488	IF	IF	+		
s1494	IF	IF	+		
s1a	LR	LR	+		
s208	LR	LR	+		
s27	LR	LR	+		
s298	~C	LR			+
s386	LR	LR	+		
s420	LR	LR	+		
s510	LR	LR	+		
s8	LR	LR	+		
s820	LR	LR	+		
s832	LR	LR	+		
sand	LR	LR	+		
shiftreg	LR	LR	+		
sse	LR	LR	+		
styr	LR	LR	+		
tav	C	C	+		
tma	LR	LR	+		
train11	LR	LR	+		
train4	LR	LR	+		

ple, encode internal states in such a way as to reduce the power consumption with increase the frequency of the input signal).

6. Conclusions and future work

In presented paper examined the relationship between power consumed by a FSM and the probabilities of ones on the input lines. The results were presented in the form of graphs and their classification done. Partially confirmed the hypothesis that the characteristics of the power consumption as a function of the likelihood corresponds to the Gaussian distribution (56% of the graphs were classified as class 1, 1L and 1R).

Detected a big impact of encoding of internal states of the FSM in the shape of a graph of power dependence on the probabilities of ones on input lines, and thus the assignment to the class. Over 30% of all cases were classified into two different classes on the use of two forms of encoding: binary and one-hot.

Examined the relationship power consumed by a FSM on the probability of changes in the value of the inputs. The results were presented in the form of graphs and their classification done. The encoding had a big impact on the dependence of power on frequency of input signals changes - graphs of 7 examples (less than 14%) were assigned to different classes using different methods of encoding (binary and one-hot). Some graphs are classified into classes LF and IF, in which the frequency increases with decreasing power.

Therefore, it is possible to obtain the desired power consumption characteristics depending on the frequency of the input signal changes by using a FSM equivalent transformations and related forms of encoding the internal states of a FSM.

References

[1] S. Yang, Logic Synthesis and Optimization Benchmarks User Guide:Version 3.0, "Technical Report", Microelectronics Center of North Carolina, 1991, 43 p.

[2] L. Benini, G. De Micheli, State Assignment for Low Power Dissipation, IEEE Journal on Solid-state Circuits, Vol. 30, No. 3 (1995), pp. 259-268.

[3] C.-Y. Tsui, J. Monteiro, M. Pedram, S. Devadas, A.M. Despain, B. Lin, Power Estimation Methods for Sequential Logic Circuits, IEEE Transactions on VLSI Systems, Vol. 3, No. 3 (1995), pp. 404-416.

[4] M. Pedram, Power simulation and estimation in VLSI circuits, "The VLSI Handbook". Edited by W-K. Chen, The CRC Press and the IEEE Press, 1999.

[5] S. Chattopadhyay, Low Power State Assignment and Flipflop Selection for Finite State Machine Synthesis – a Genetic Algorithmic Approach, IEE Proceedings – Computers and Digital Techniques, Vol-ume: 148, Issue: 45, 2001, pp. 147-151.

[6] A. Tiwari, K.A. Tomko, Saving Power by Mapping Finite-state Ma-chines into Embedded Memory Blocks in FPGAs, Proceedings of Design, Automation and Test in Europe Conference and Exhibition, 16-20 Feb. 2004, Vol. 2, pp. 916-921.

[7] V. Salauyou, T. Grześ, Obliczanie mocy układów sekwencyjnych, "Elektronika" nr 4 (2005), str. 25-27.

[8] V. Salauyou, T. Grześ, Classification of dependence of power dissipated by sequential circuit on input signal parameters, „Image analysis, computer graphics, security systems and artificial intelligence applications", Wyższa Szkoła Finansów i Zarządzania, Białystok 2005, pp. 139-149.

[9] W.-T. Shiue, Novel State Minimization and State Assignment in Finite State Machine Design for Low-power Portable Devices, Integration, the VLSI Journal, Volume 38, Issue 4 (April 2005), pp. 549-570.

[10] Y. Xia, X. Ye, L. Wang, W. Tao, A. Almaini, A Uniform Framework of Low Power FSM Partition Approach, International Conference on Communications, Circuits and Systems Proceedings, Guilin, 25-28 June 2006, Volume 4, p. 2642-2647.

[11] V. Salauyou, T. Grzes, Zavisimost' potreblâemoj mošnosti konečnyh avtomatov ot veroâtnosti izmeneniâ vhodnyh signalov, 6. meždunarodnaâ konferenciâ CAD DD'2007, Minsk, 14-15 noâbrâ 2007 g., str. 282-300.

[12] V. Salauyou, T. Grzes, FSM State Assignment Methods for Low-power Design, Proceedings of 6th International Conference on Computer Information Systems and Industrial Management Applications: CISIM'2007, Ełk, June 28-30, IEEE Computer Society, Los Alamitos 2007, pp. 345-348.

[13] T. Grzes, V. Salauyou, I. Bulatava, Power estimation methods in digital circuit design, Optoelectronics, Instrumentation and Data Processing, 2009, V. 45, No. 6, pp. 576-583.

[14] T. Grzes, V. Salauyou, I. Bulatava, Algorithms of coding the internal states of finite-state machine focused on the reduced power consumption, Radioelectronics and Communications Systems, 2010, V. 53, No. 5, pp. 265-273.

KLASYFIKACJA POBORU MOCY AUTOMATÓW SKOŃCZONYCH

Streszczenie: Zmniejszenie zużycia energii układu cyfrowego można uzyskać na wiele sposobów. Układy scalone wykonane w technologii CMOS zużywają moc, gdy stan na wyjściu elementu logicznego (bramki lub przerzutnika) zmienia się na przeciwny. Dlatego zmniejszenie liczby takich zmian prowadzi do zmniejszenia zużycia energii. W niniejszym artykule zaprezentowano badania zależności mocy pobieranej przez automat skończony od prawdopodobieństw występowania jedynek logicznych na liniach wejściowych i prawdopodobieństwa zmiany wartości na liniach wejściowych. Zaproponowano również klasyfikację wykresów uzyskanych dla wymienionych zależności. Klasyfikacja ta może być zastosowana do oceny wyników procesu redukcji energii oraz sprawdzenia zachowania automatu skończonego przy zmianie właściwości statystycznych sygnałów wejściowych. Zaproponowana klasyfikacja może być również użyta do stworzenia nowych metod i algorytmów zmniejszenia poboru mocy w automatach skończonych.

Słowa kluczowe: moc w automatach skończonych, automaty skończone, klasyfikacja mocy