PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 17 No. 2 September 2013 pp: 79-84

Solid State-Based On-Load Tap-Changer Control

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ABSTRACT

This paper develops a new scheme for accurate and fast response full electronic tap changer. The proposed tap changer uses solid state relays (SSR) for each tap step. The proposed scheme is simulated using Proteus program for a primary design process. Different voltage levels are tested to verify accuracy. The tap changer events could be used as a history in load forecasting studies for substations. A hardware prototype of the proposed OLTC is implemented in this work. Five SSRs operate as the switching taps for 0.5 KVA, 180/110V single phase transformer. The visual basic program is used to monitor and control the voltage regulation process throughout a personal computer. The simulations and experiments results ensure accuracy and high-speed of the new module ranging between 15 ms to 25 ms for each step change.

KEYWORDS*:* Load frequency control; PID control; Egyptian Power System; robust control; bacterial foraging algorithm.

1. INTRODUCTION

On-load tap changer (OLTC) in power transformers are an essential part of any modern power system, since it allow voltages to be maintained at desired levels despite the load changes. Power system planning is impossible without using of the tap changer in practice. Although the first OLTCs were developed in the early part of this century, modern versions still have not altered radically from these designs and in essence, they are complex mechanical device.

The problem of conventional tap changer in the mechanical structure is the complicated gear mechanisms of selectors and diverters switches. These arrangements are slow in response, cause corrosion in the conductors and deterioration of insulating oil, thus. It is necessary to implement tap changer that solve these problems and improve voltage regulation process during the load changes.

High controllability advantages of power electronic switches lead to their application in the tap changer of power transformers [1]. Using such switches leads to quick operation of the tap changer. Moreover, their application reduces maintenance and repair costs of tap changer. In recent years, there have been rapid developments in proposed schemes for solid state tap changer [2-6].

A new type of GTO thyristor assisted tap changer is outlined and discussed in [2]. Instead of using oil-immersed contact and complicated mechanical drive, a vacuum switch was used. Testing on a 300 kVA transformer, it has shown the system to work at all power factors and for all tap changes. The tap changer has a fast response and a low power loss. It has the potential of having a long service life with lower maintenance costs and a higher reliability than present day commercial tap changers.

Bashi [3] maintained the voltage supply by changing tap setting via microcontroller through triac assisted selector. The system takes approximately 0.44s to response to the load changes.

The design stages of the power and control parts in low-power (5 KVA) are shown in [4]. The Prototype transformer for electronic tap-changer was described. The experimental results are shown that with sudden change of input voltage from 240 to 188 V or from 170 to 220 V, the output voltage of the transformer tends to a stable voltage 220 V. In other words, taking into account the rapid change of the input voltage, the regulation time is extremely shorter than that of the corresponding mechanical tap-changer.

In reference [5], a thyristor has been used to facilitate switching in mechanical tap changers. The switching logic for a transformer solid-state tap changer has been developed and applied to a laboratory model giving satisfactory operation over the complete power-factor spectrum under normal operating conditions.

An on-blocking supervisory control for an under-load tap-changing transformer in auto/manual mode of operation is discussed in [6]. The state size of the supervisory controller has been reduced for easier implementation. The PLC implementation problems are solved by a heuristic method.

A prototype was built with triac switches as the switching devices and AVR microcontroller as the control circuit is presented in [7]. A fully electronic tap changer with four taps for 2 KV A, 220/1200V single phase transformer is designed and built.

A fast on-load tap changing regulator used to correct unbalanced voltages is presented in [8]. This regulator uses the semi natural commutation in order to improve the response. These topology injects the voltage in only one phase in order to balance the three phase system.

In this paper, the improvement is concentrated on maintaining the voltage supply by changing tap setting via microcontroller and/or personal computer (PC) through solid state relay assisted selector. The obtained

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results from the experimental work show that the proposed tap changer is able to monitor the voltage supply and maintain it within the specified range. The new model gives a visual environment to the operator and operates manually and/or automatically.

2. THE PROPOSED SOLID STATE-BASED TAP CHANGER MODEL

The proposed full electronic OLTC is shown in Fig. 1. The solid state relays (SSRs) are used as the switching device to turn on the selected tap of the power transformer.

The microcontroller with its loaded software acts as the triggering element to the SSRs. Step-down transformer and transistors are connected between the input and output of the microcontroller, respectively, to isolate the low voltage circuit of the microcontroller from the high voltage circuit of the power transformer.

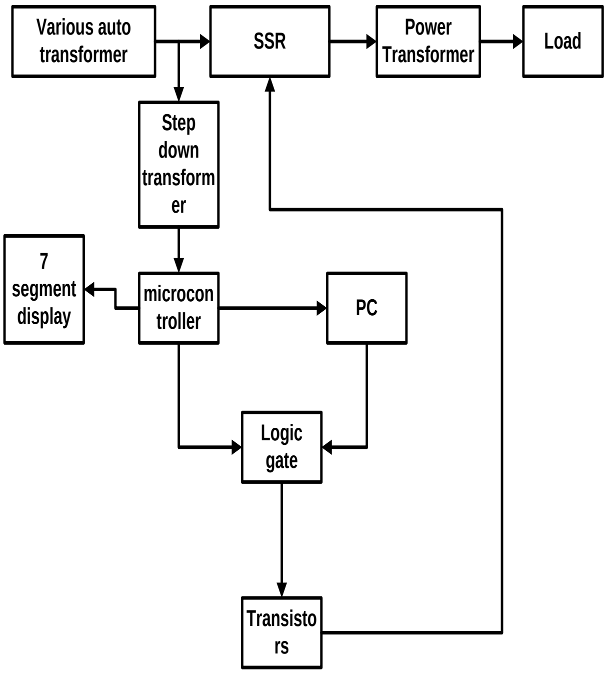

Fig.1: block diagram of the proposed OLTC model

The PC will be used to operate the system with visual environment. The PC can operate the model when the microcontroller is damaged. The 7 segments display is used to illustrate the position of the tap changer when the PC is not operated.

The output voltage of the transformer depends on two factors; the input voltage to the transformer from the system and the load at the consumer. At normal operation, the transformer is receiving 180 volt at the primary side and deliver 110 volt at the secondary side. At each point in primary side, one SSR is used. At normal operation, the tap changer is set at step three [T3]. Any change in the input voltage cause a step change in the tap to keep the value of output voltage at 110 volt. The circuit diagram of the proto type model is shown in fig. 2.

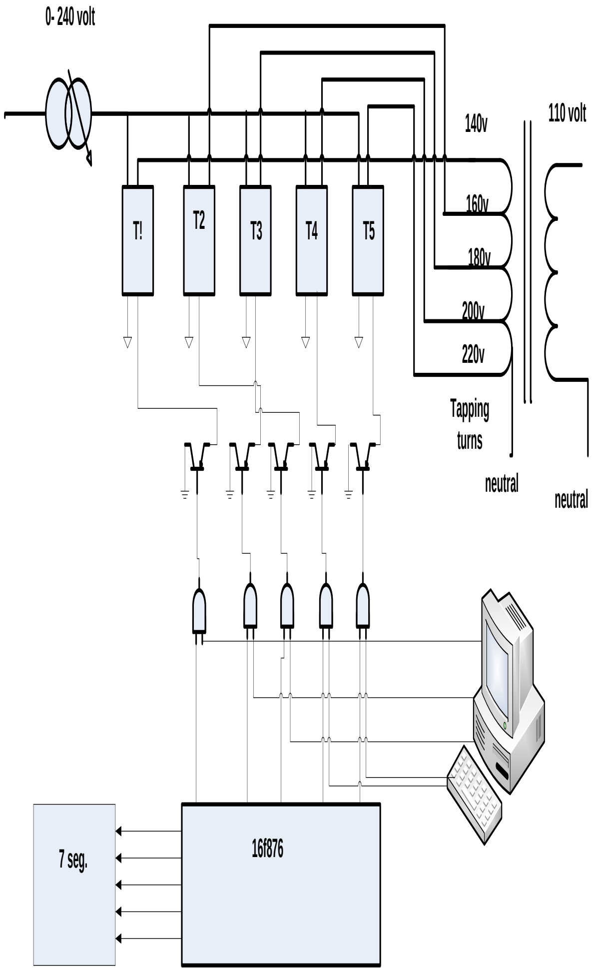

Fig.2: the circuit diagram of the prototype model

The control circuit is the important part of this module. An input voltage signal is taken and analyzed to determine the appropriate decision. The analogue signal will enter to the microcontroller (pic 16f876) from the step down transformer at port A2. Port B and port C are the outage of the pic. Port B is used to operate the seven segments that used to clarify the current status of the tap changer. The flow chart of the 7 segments display is shown in Fig. 3.

An analog-to-digital converter (ADC) is a device that converts a continuous physical quantity (usually voltage) to a digital number that represents the quantity's amplitude. The conversion involves quantization of the input, so it is necessarily to allow a small amount of error. In this module, the ADC built in the microcontroller is used. The flow chart shows in Fig.4.

The output of port C will have two-ways, first to AND Gate and the second to the PC. After entering the signal to the PC, the Visual Basic program will operate the system. The appropriate decision is taken and a control signal is out via the specified port. Signals from the PC and the microcontroller are assembled through AND gate. The outage of the AND gate is entered a transistor. Transistors work as switches to operate the suitable SSR. The control circuit of this project can be illustrated in fig.5.

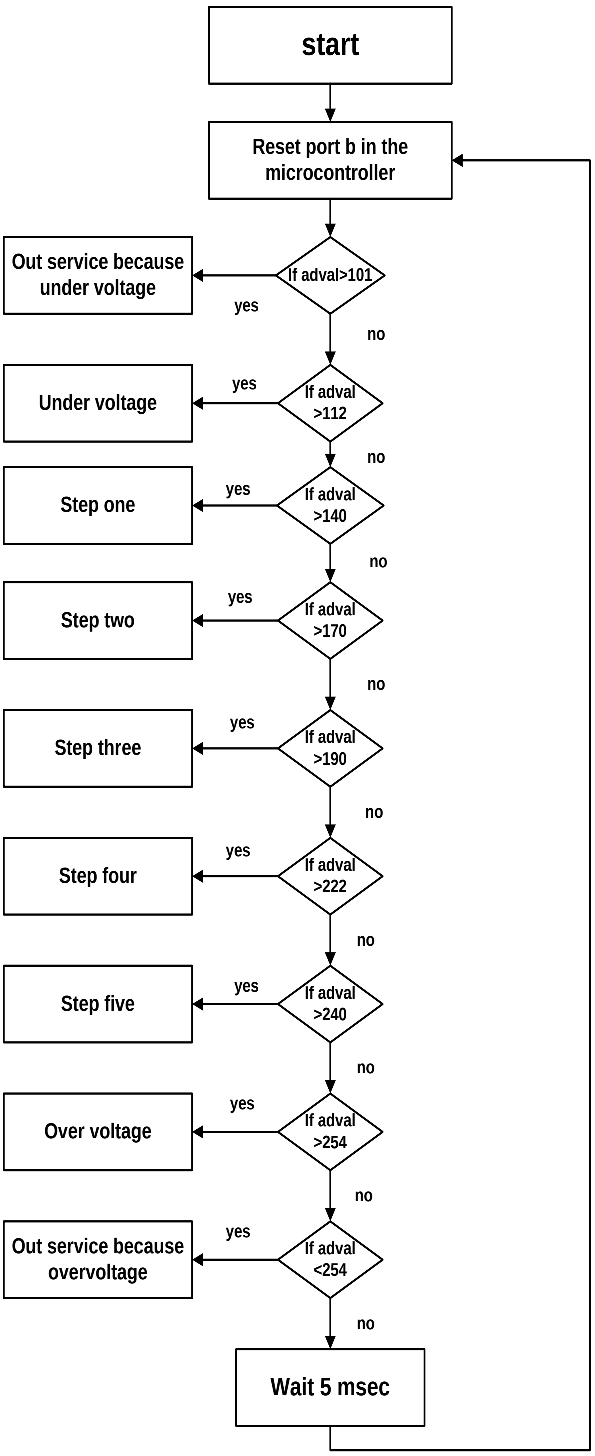

Fig.3: The flow chart of the 7-segment display.

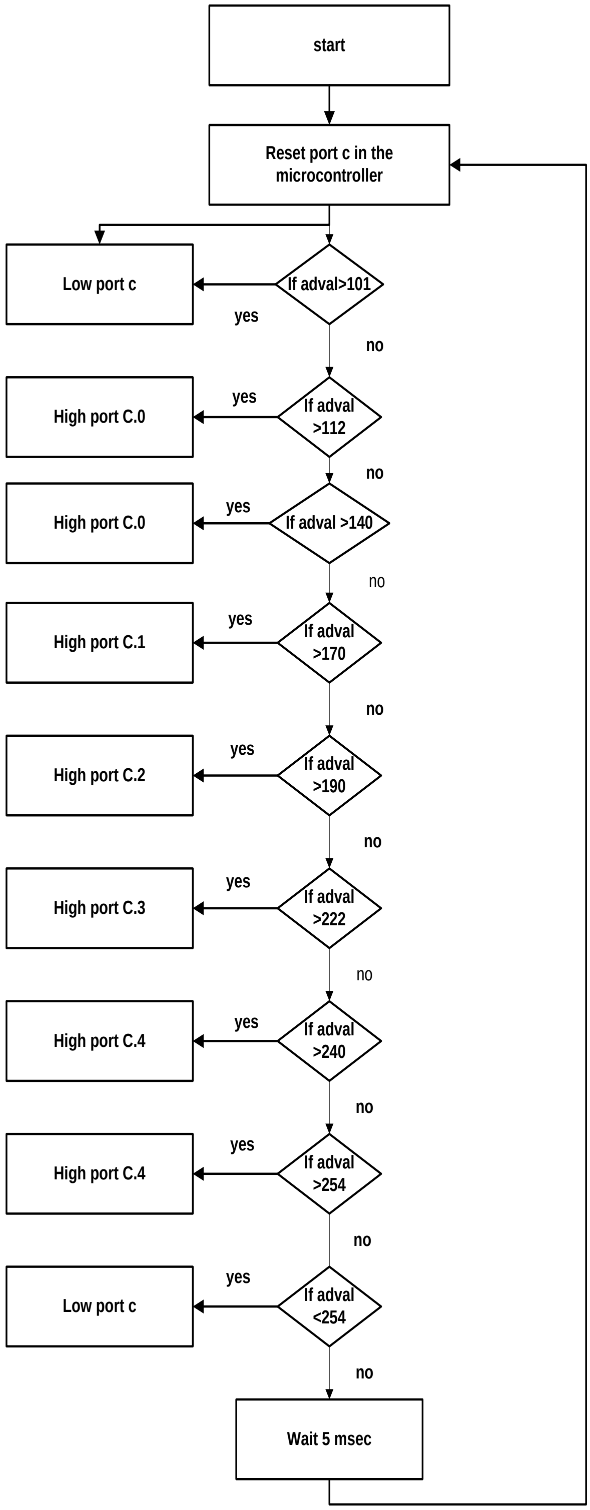

Fig.4: The flow chart of ADC.

The AND gate is used to assemble electrical signals emerging from the PC and the microcontroller [6]. The aim of the AND gate can be achieved in the following points:

1 – Prevent circulating current through the valves of the SSR when the computer restarts.
2 – The possibility of running the microcontroller and the computer at the same time.
3 – The system could be operated manually if the microcontroller has a malfunction.

In this module transistor TIP 3055 will be used to govern the input of the SSR [8].

3. SIMULATION RESULTS

The module circuit design is simulated using Proteus 7.1 SP2 program as shown in Fig. 6. Proteus program represent the actual environment to run the microcontroller. Figure 6 illustrate the connection of seven segment, the outage of the microcontroller to the

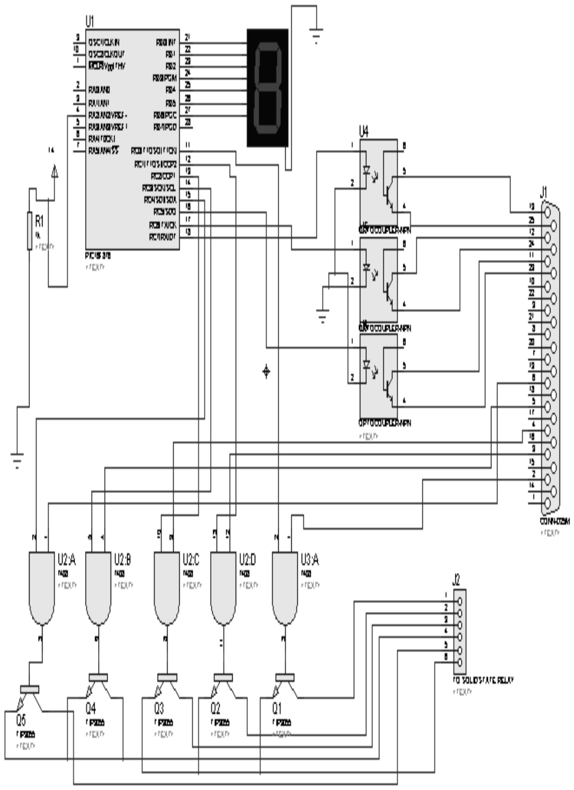

Fig.5: The control circuit of the prototype

PC and the outage to the AND gate that displayed by LEDs. It is shown in Fig.6 that if the input voltage from the adaptor transformer is 4 volt, the tap will be at step four.

Simulation results for different input voltages and simulation voltages are shown in table1. The input voltage is the voltage that enters to the prototype transformer through the SSRs. At the normal operation the transformer will be operated to change the 180 volt at the primary side to 110 volt at the secondary side. Any change in the input voltage, will change the tap step to maintain the output voltage at a constant value.

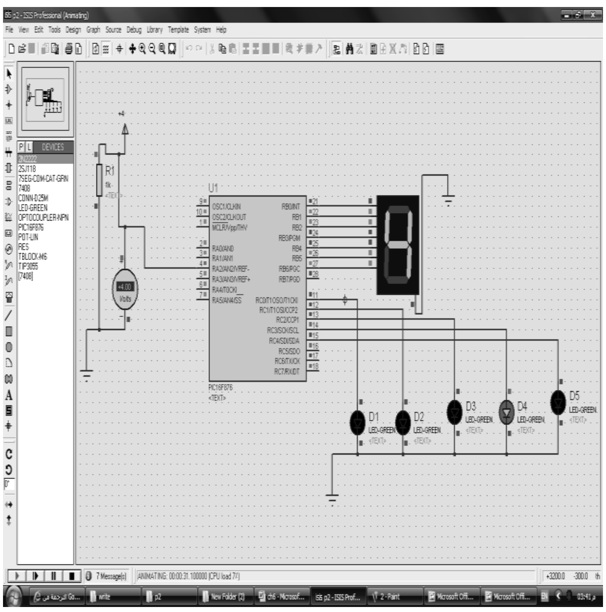

Fig.6: The simulation of the module

Table 1: The simulation results.

input voltage	Simulation voltage	Tap 1	Tap 2	Tap 3	Tap 4	Tap 5
130	2.1	on	off	off	off	off
140	2.4	on	off	off	off	off
160	3	off	on	off	off	off
180	3.5	off	off	on	off	off
200	4	off	off	off	on	off
220	4.6	off	off	off	off	on
230	4.75	off	off	off	off	on

The simulation voltage is the voltage that enters to the microcontroller and converts from analogue signal to digital signal. If the simulation voltage is from 2.1volt to 2.3 volt, the tap will be at step one. Also, if the simulation voltage is from 4 volt 4.5 volt, the tap will be at step five.

From Table 1, it can be seen that no circulating current will be appeared in this module

4. HARDWARE IMPLEMENTAION OF THE PROPOSED SCHEME

Testing is very important in the initial operation. to avoid blunders. The testing process is done by testing each part of the module separately, after that overall module will be tested and also review all connections accurately. Because measuring the response time of the new module is very important, software program is designed by VB program to measure the speed of on and off actions. The circuit diagram for testing the speed shows in Fig.7.

The time delay of SSR is between 10 and 20 ms. Fig.8 shows the different measured times of solid-state relay to take one action. The total time for the proposed scheme to operate one tap changer step is between 15 and 25 ms when adding the time delay of the microcontroller software to the solid-state relay delay time. Thus, the new module is faster than that proposed by Bashi [3] (440 ms).

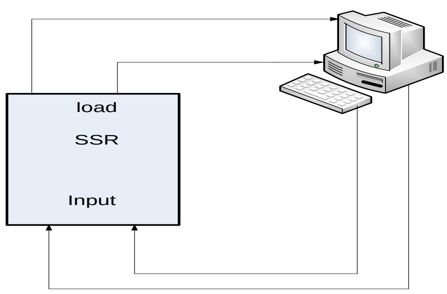

Fig.7: Circuit diagram of testing SSR

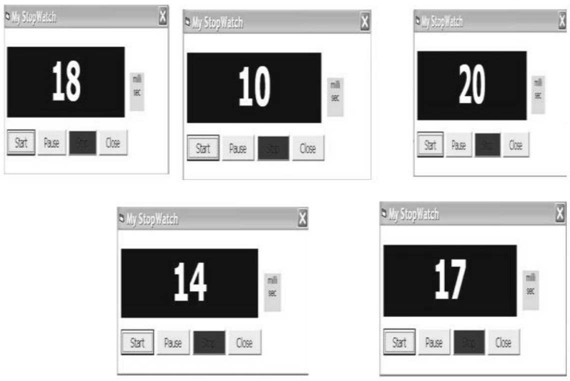

Fig. 8: Testing the time delay of solid-state relay.

The program designed using the VB will operate the system on two key sectors as shown from the flow chart of Fig.9.

- **The automatic control system.**
  This system is run either by computer or through the microcontroller. Both systems use the grouped signals through the AND gate, if the computer has any malfunction, the system will automatically works through the microcontroller. It is possible to know the current step of the tap changer using the 7 segment display.

- **The manual control system.**
  When the microcontroller is failed, the ordinary voltmeter is used to operate the system manually through the computer. The results of the prototype module are shown in table 2.

The following could be drawn from Table 2:

1- If the input voltage is 140 volt the outage voltage will be 110 volt and the tap will be at step one.
2- There is no circulating current appeared.
3- Any change in the input voltage cause an automatic tap change to maintain a stable voltage for the consumer.

The hardware prototype model is shown in Fig.10.

Fig.10: The hardware prototype module

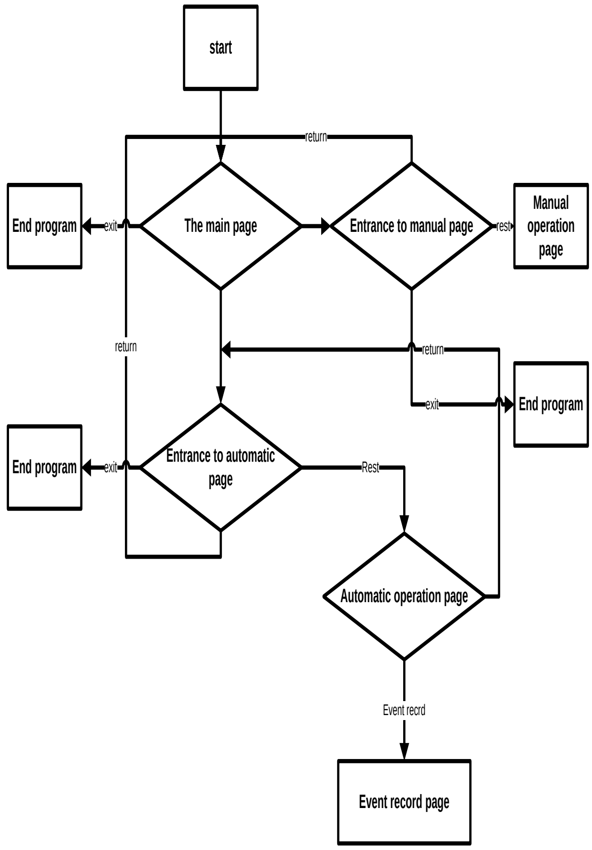

Fig.9: The flow chart of VB program

5. CONCOLUSIONS

This paper presented a developed full electronic tap changer module. The following conclusions can be made:

1- The module simulated using Proteus program for a primary design process. Different voltage levels are tested to verify the accuracy of the module.
2- The visual basic program is used to monitor and control the voltage regulation process throughout a personal computer. The tap changer events could be used as a history in load forecasting studies for substations.
3- The main advantage of the developed tap changer that it permits only one point of tap changer to work at a time.
4- A hardware prototype of the proposed on load tap changer is implemented in this work. Five solid state relays operate as a switching taps for a 0.5 KVA, 180/110 V single phase transformer. A microcontroller is used to convert analogue signals to digital signals.
   The model is tested and operated in difficult operating conditions, so any change of the output voltage will be treated by the model.
5- The experiments ensure high-speed of the new module ranging between 15 ms to 25 ms for each step change.

Table 2: The results of the prototype module

input voltage	output voltage	tap1	tap2	tap3	tap4	tap5
120	0	off	off	off	off	off
130	101	on	off	off	off	off
135	107	on	off	off	off	off
140	110	on	off	off	off	off
145	114	on	off	off	off	off
150	118	on	off	off	off	off
155	108	off	on	off	off	off
160	111	off	on	off	off	off
165	115	off	on	off	off	off
170	118	off	on	off	off	off
175	107	off	off	on	off	off
180	110	off	off	on	off	off
185	114	off	off	on	off	off
190	116	off	off	on	off	off
195	107	off	off	off	on	off
200	110	off	off	off	on	off
205	113	off	off	off	on	off
210	116	off	off	off	on	off
215	108	off	off	off	off	on
220	110	off	off	off	off	on
230	115	off	off	off	off	on
240	120	off	off	off	off	on
248	0	off	off	off	off	off

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