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Microcontroller-based Fast On-load Semiconductor Tap Changer for Small Power Transformer

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Abstract: Power quality is one of the most talked about topics these days. Both the power utilities and customers are quite concern with the quality of the power supply, whether it be the power generated by the power utilities or the power consumed by the customers respectively. They need these supplies to be at its optimum value so that the cost is efficient; otherwise problems such as over voltage, under voltage, voltage swell, voltage sag, noise and harmonic caused by the disturbances in power supply could be disastrous. Several methods have been suggested and applied as the solution to these problems. One of the methods is by employing on-load power transformer with tap changer, where the output voltage of the power transformer remains constant irrespectively to the input voltage or variation of the load. The existing mechanical on-load tap changing power transformer has few disadvantages, as it is slower, produces arching each time the tap setting is changed and needs regular maintenance. With the emergence of high power semiconductor devices such as triac, problems associated with the mechanical on-load tap changing power transformer have been properly rectified. In this study, a small prototype consisting of triacs as the switching devices and microcontroller as the triggering circuit has been constructed. The results obtained from this study show that the prototype has a faster time response of approximately 0.4s for the circuit to react to any load changes, produces no arching problems as it has no mechanical contact and requires no maintenance. The system has been tested for reliability and proven to be reliable in maintaining the output voltage of the system.

Key words: Voltage regulator, semiconductor tap changer, microcontroller applications, on-line tap changer

INTRODUCTION

The role of the power utility is not just limited to provide the power supply to the customer but also to ensure a good quality of power supply with minimum disruptions in terms of sags, swells, over voltage, under voltage, imbalance, noise and harmonics. These disturbances are definitely undesirable to most industrial and commercial end users. Several measures have been taken to rectify these problems, such as by employing voltage regulators, capacitors and dc stored energy systems but there is still room for lot more to add on. In this paper, focus is being given to power transformer with modern tap changer. There are two types of transformers with tap changers; on-load and off-load. The former is preferable, as there is no disconnection of transformer when changing the tap setting, thus the operation of supplying the load demand is remained uninterrupted. The off-load tap changers have become almost in today's power quality conscious society[1-3].

The main problem of existing or conventional tap changer is mainly due to its mechanical parts, comprising of complicated gear mechanisms of selectors, diverters and switches. They are slow and susceptible to contact wear condition and deterioration of insulating oil, thus requires regular periodic maintenance. It is also sluggish to impact loading and sudden load rejections. On-load tap changing transformers are an essential part of any modern power system, since they allow voltages to be maintained at desired levels despite the load changes. Although the first on-load tap changers 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 devices that need to be replaced with semiconductor devices[4,5].

The transformer on-load tap changer arcs each time the tap changes its setting. Each operation contributes to the deterioration of the transformer oil. To address this situation, a new diverter switch arrangement is employed by the use of thyristors pairs across arcing contacts, as reported by Roberts and Ashman[6]. It was further developed to a single diverter resistance and then to inverse parallel thyristor pairs, which are connected across a set of mechanical switch contacts[7]. A new design scheme for tap changer had been outlined and discussed by Shuttleworth *et al.*[8]. Instead of using oil-immersed contact and complicated mechanical drive, a vacuum switch and bistable electromechanical actuators were used instead. These vacuum switches have the advantages of high power handling capability and can have a long life, thus, making them suitable for the use as the selector.

Modern GTO thyristors are now approaching the power ratings of large standard thyristors and can eliminate the need to monitor power factor, since they are able to turn off with a forward applied voltage. Hao Jiang *et al.*[4] have proposed a faster form of GTO assisted tap changer with the advantage of reduced transformer outages. With this new scheme, it is intended that the speed of the vacuum switch moving contact is controllable since fatigue in the stainless steel bellows is the prime limitation and reverts to fast operation during a system fault[9,10].

The application of semiconductor or solid state devices in designing the tap changer have the advantage of faster response, almost virtually maintenance free and better performance in term of power quality when compared to its conventional counterpart. The only setback of solid state devices is cost efficiency and high conduction loss. Furthermore, as solid-state devices must permanently connect in the circuit, some sort of protection against high-voltage surges traveling down the transformer winding is required[7,8]. Two forms of alternative design of tap changer have been proposed; fully electronic and electronically assisted. Fully electronic tap changer relies upon thyristor technology, while electronically assisted tap changer attempt in maintaining the mechanical essence of the standard tap changer but with improved maintainability by incorporating thyristors to eliminate contact arching. Fully electronic schemes are inherently fast and maintenance free, but expansive to construct when compared to its thyristor assisted counterpart, but it does not address the problem of operating speed and mechanical reliability[11]. Other than the improvement made on the tap changer designs, a control algorithm using Discrete Cycle Modulation (DCM) and Fuzzy Logic Controller (FLC) has also been explored and tested[12,13]. In this study, the improvement is concentrated on maintaining the voltage supply by changing tap setting via microcontroller through triac assisted selector. The results obtained from this experiment shows that the proposed semiconductor tap changer is able to monitor the voltage supply and maintain it within the specified range. The system takes approximately about 400 ms to response to the load changes.

SEMICONDUCTOR TAP CHANGER

The main interest in this study was to design a semiconductor tap changer with a small prototype constructed as the model of the operation. The layout of the prototype is as shown in Fig. 1. This prototype semiconductor tap changer consists of a triac circuit as the switching device to turn on the selected tap of the power transformer. As displayed in Fig. 1, the low voltage circuit is separated from the high voltage circuit in order to protect the microcontroller from damage.

Figure 2 shows the detailed block diagram for the semiconductor tap changer used in this work. It has the same construction as in Fig. 1, with the insertion of few extra devices to provide a better accuracy and safety for the system. The input of the microcontroller is protected from the high voltage by connecting it to a step-down transformer. Furthermore, this step-down transformer helps in bringing down the transformer's output voltage to an acceptable value for microcontroller operation. This reduced voltage is then compared with the reference voltage before feed into the triggering circuit. The output of the microcontroller is also connected to an isolator for the same purpose as earlier. There are a 10/6 V step-down transformer, rectifier, peak detector, filter and opto-transistor forming a feedback loop circuit. The function of this feedback loop is to convert the 110 V AC line voltage to an acceptable DC level voltage for the microcontroller operation and provide a protection from damaging the microcontroller. Rectifier converts the AC voltage signal to DC voltage signal. However the output

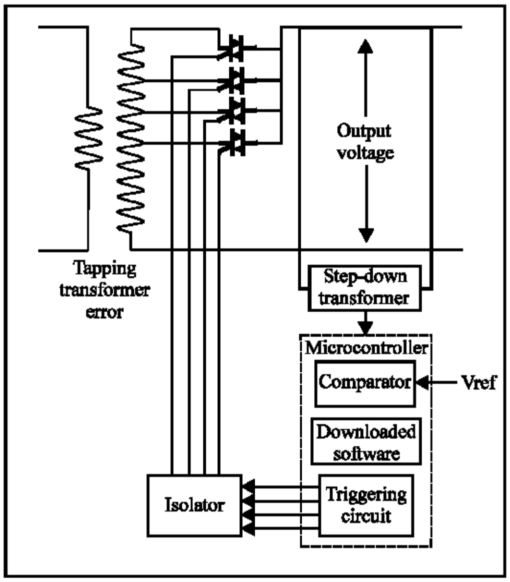


Fig. 1: Layout of the on-load electronic semiconductor tap changer

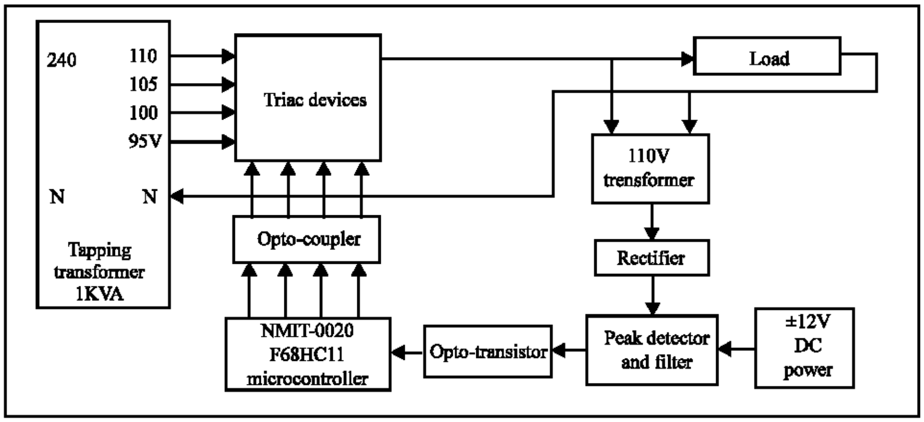


Fig. 2: Block diagram of semiconductor tap changer for power transformer

of the rectifier is not constant but it has some ripples. In order to achieve better signals, peak detector and filter is employed. Peak detector will detects the peak value of the rectifier's output signal and gives a constant DC equivalent voltage. Filter will then filtered out any noise and further improve the signals so that it is free from any ripples and within certain range of frequencies. While the opto-transistor acts as an electric isolator to the input of the microcontroller.

NMIT-0020 F68HC11 microcontroller is used as the logical central process control to process the input signal and produce a suitable output signal according to the program loaded into the microprocessor. The microcontroller acts as a trigger by injecting pulses to the selected triac representing the appropriate taps. At any instant, only one triac will be in its ON state while others are turn off.

The output signal of the microcontroller is feed into the selected opto-coupler input. Opto-coupler protects the output of the microcontroller from the high voltage value of the transformer if it is connected directly with the triac input pin. It also functions to maintain the ON-OFF switching operation of the triac. When the microcontroller has samples the DC voltage and determines the appropriate tap setting to maintain the voltage, it will generates pulse signal to the designated opto-coupler. This opto-coupler will then activate the triac connected to it. Once the triac is ON, it will stays ON until the gate terminal voltage of the triac falls below the holding current. The rest three triac is at its OFF condition and will continues to be in this condition until the microcontroller decides to change its tap setting based on the output of the load. So, when the microcontroller senses changes in the load voltage, it will compute the new tap setting and gives an appropriate pulse to the selected opto-coupler. It will then turns on the connected triac and the load voltage will returns to normal.

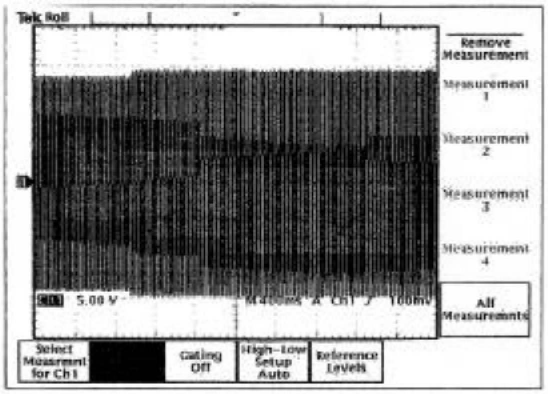
The software loaded into the microcontroller is written using PROCOMM. It samples the input given to the microcontroller and compares the value with the determined value written in the program. The software has been given a set value of 100 V. The signal is first converted to digital value by the internal analog-to-digital converter before the microcontroller could process the information. If the value is 10% more or 10% less than the nominal value, the microcontroller will quickly change the tapping to a lower or a higher taps setting respectively. Microcontroller will continues changing the setting to maintain the voltage within the set value. If the tap setting is at its maximum or minimum, alarm signal will be generated and indicated by flashing the LEDs. Otherwise, the taps setting will remains unchanged.

RESULTS AND DISCUSSION

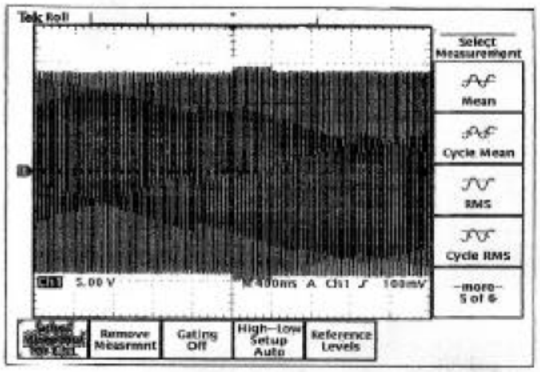
There are 4 taps setting; tap 1, 2, 3 and 4 arranged in increasing tap setting, which are 95, 100, 105 and 110 V, respectively. The input voltage to the tapping transformer is set to 240 V and the output is 100 V. The load current is 5A. At this condition, the taps setting is at position 2 (tap 2 is at ON state and others are OFF). The prototype was tested for its reliability by measuring the output voltage of the transformer when the input voltage was increased steadily. Each time the tap setting changes its setting, the output voltage was recorded. The increment stopped when the alarm indicator voltage too high lighted up. Then the steps are repeated with the input value decreasing until the voltage too low alarm indicator is turn on. The nominal output voltage is 100±5 V. From the Table 1, it is shown that as the output voltage was increased, the microcontroller decreased its taps setting by 1 in order to maintain the output voltage at nominal value. When the output value exceeds 105 V.

Table 1: Result from the testing operation of semiconductor tap changer

Input voltage (V)	Output voltage (V)	Tap 1 95 V	Tap 2 100 V	Tap 3 105 V	Tap 4 110 V	V low	V high
240.3	99.8	Off	On	Off	Off	Off	Off
252.8	100.1	On	Off	Off	Off	Off	Off
263.5	105.2	On	Off	Off	On	Off	On
260.1	103.7	On	Off	Off	On	Off	Off
242.2	100.5	Off	On	Off	Off	Off	Off
230.0	99.8	Off	Off	On	Off	Off	Off
220.8	100.1	Off	Off	Off	On	Off	Off
207.5	94.0	Off	On	Off	On	On	Off
211.8	96.1	Off	Off	Off	On	Off	Off
231.1	100.5	Off	Off	On	Off	Off	Off



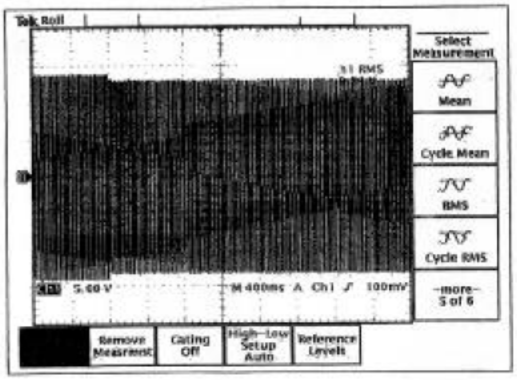
a) Switching on heavy load without microcontroller semiconductor tap changer



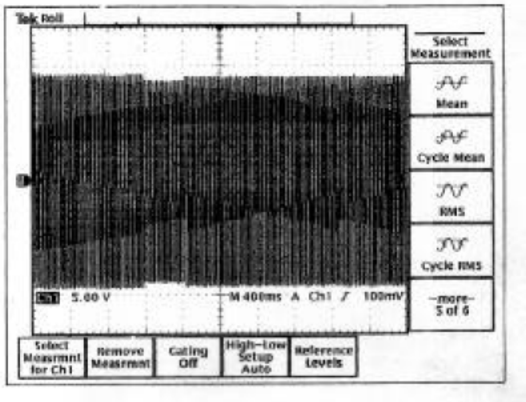
b) Switching on heavy load with microcontroller semiconductor tap changer

Fig. 3: Switching on a heavy load with and without microcontroller tap changer

When the output voltage was decreased, the microcontroller increased the taps setting by 1 (changing from tap 2 to 3) and continues to do so until the output voltage is within 100 V. If the input voltage falls below 95 V, 'V low' indicator lights up, showing that the system is in dangerous state. From this table, it clearly indicates that the microcontroller manages to maintain the system at its nominal voltage and it is reliable.



a) Heavy load rejection with out controller



b) Heavy load rejection with controller

Fig. 4: Voltage waveforms during heavy load rejection with and without controller

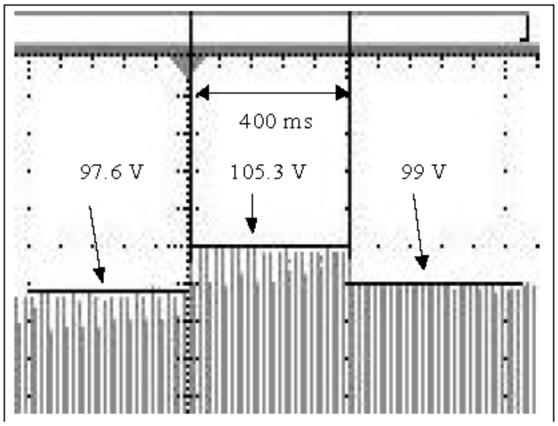


Fig. 5: Detail of voltage correction

The system was also tested with a heavy load at the secondary side switched on. The output waveform were in Fig. 3a. As the heavy load is switched on, there is a voltage drop for a short period of 440 ms. The semiconductor tap changer detects the situation and changed the tap setting from tap 2 to 3, hence the voltage increased to the permissible level as displayed in Fig. 3b. The system was then tested with switching off a heavy load at secondary side.

As the heavy load is switched off, the voltage increases for a short period of 400 ms. The semiconductor tap changer detects the situation and changes the tap setting from tap 3 to 2, hence the voltage decreased to the permissible level as in Fig. 4. Figure 5 shows the closed up voltage correction when the voltage increases due to switching off heavy load.

CONCLUSIONS

Any variation of the output voltage of the power transformer will be detected by the microcontroller, which in turn computes and executes necessary command instruction to be passed on to the appropriate triac. The semiconductor tap changer will change the tap position if the variation is out of the permissible range. Thus the voltage of the system could be maintained at nominal value. From the result, the semiconductor tap changer could be associated as an automatic electronic on-load tap changer for power transformer to improve the voltage regulation of the power system during the variation of system voltage. Distinguished characteristics of this semiconductor tap changer are fast response and less negligible spark during tap changing process.

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