Solid-State On Load Tap-Changer for Transformer Using Microcontroller

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***Abstract*- The on-load tap changing (OLTC) regulators have been widely used since the introduction of electrical energy. They ensure a good regulation of the output voltage in presence of large variations of the input voltage with typical response time from several mili-seconds to several seconds. Earlier mechanical type of on load tap changers were into practice. But they had considerable limitations and drawbacks like arcing, high maintenance, service costs and slow reaction times. In order to overcome these limitations and drawbacks electronic (or solid-state) tap-changers were developed. The continuous growth of power semiconductor devices, such as the insulated gate bipolar transistor (IGBT), triac, thyristor, has allowed the development of quick operating OLTC regulators which is also helpful in fixing other problems in the ac mains, like flicker and sags. The major idea in the solid-state-assisted tap changer is that solid-state switches with more controllability, operates during the tap-changing process instead of mechanical switches which helps in reducing the arcing phenomena during the tap-changing process. In this paper implementation of a fast OLTC regulator is presented. The control strategy is Microcontroller-based, ensuring flexibility in programming the control algorithms. The experimental results demonstrate that the fast OLTC is able to correct several disturbances of the ac mains besides, the long duration in variation in time is much lower than the one corresponding to the traditional regulators.**

***Keywords* - on-load tap changer, voltage regulator, microcontroller applications, microprocessor applications, OLTC.**

I. INTRODUCTION

The main application of a tap-changer regulator is to regulate the amplitude of the output voltage. The major objective of the controller in the tap-changer system is to minimize the fluctuation of voltage amplitude with respect to the reference voltage of the regulation bus. This bus should be far from the secondary of the transformer. The controller must regulate the voltage within a given range [1]. Power quality is also one of the most important thing these days. Both the power utilities and consumers are quite concerned with the quality of the power supply. This needs the 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 of these problems. One of the methods is by employing an on-load power transformer with tap changing, 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 tape changing power transformer has few disadvantages as it produces arcing, requires regular maintenance, service costs, and slow reaction times [2]. With the use of high power semiconductor devices such as triac, IGBTs, Thyristor, problems related with the mechanical on-load tap changing power transformer have been eliminated. In order to overcome these limitations and drawbacks, new circuits and configurations for tap-changers have been introduced. These may be classified into two groups [4].

1 Electronically assisted (or hybrid) on-load and
2 Fully electronic (or solid-state) tap-changers

The first circuit for the hybrid tap-changer was presented in 1996 [5]. This structure reduces the arcing considerably. However, its major disadvantage is that although two thyristors are ON over short periods during the tap-changing process, it is permanently connected to the circuit of the deviation switches and it probably gets burnt. This may therefore reduce the reliability of the system. To remove this drawback, an alternative configuration has been introduced [6]. The main idea in this circuit is that, two thyristors are connected only during the tap-changing period which improves the reliability of the system. So far, the suggested structures could reduce the arcing; using a tap-changer, quick operation of the tap-changer is desirable. In such a case a traditional tap-changer cannot respond well, while an electronic tap-changer enables to operate properly.

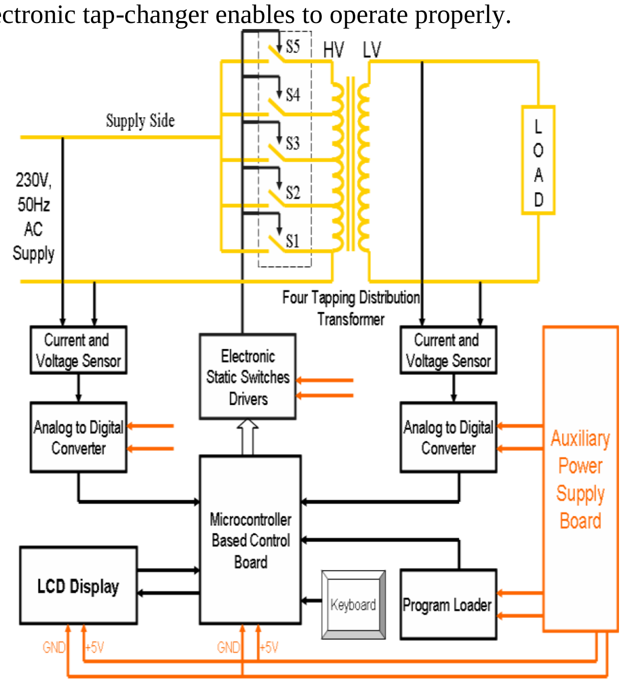

Fig. 1 Block diagram for OLTC power and control scheme

A common OLTC regulator scheme is shown in Fig. 1. Thousands of electronic regulators are currently used. Here fast OLTC regulators are built with power devices, such as SCR TYN 616 which can operate at high switching frequency. This allows correcting several problems in the ac mains, such as sags and flicker.

II. POWER STAGE IMPLIMENTATION

Here proposed topology is design by using 1KVA transformer. It can become a direct replacement of the classical regulator applied to high power levels. This allows having low costs for the used semiconductor devices and makes the fast OLTC regulator suitable for high power applications.
The main switch S1-5, which is bidirectional in current and voltage. It consists of a Double unidirectional switch (SCR). This bidirectional switch configuration has the advantage of using only one unidirectional switch, which in addition results in a simpler control. However, it has the disadvantage of higher conduction losses due to the series operation of more semiconductor devices, higher switching stress of the transistor. Also, with this configuration it is not possible to control the current flow in both directions separately, but since the regulator is operated with a two-step commutation strategy, it has no influence on the commutation process. Each main switch is controlled by the same gate signal in both possible current directions. In this case, only a two-step commutation strategy can be used, which presents the problem of a short-circuit current between taps during the commutation.
This problem can be solved by the following methods, maintaining the switch configuration [9].

- Sensing the current in order to switch at the zero crossing point
- Switching without sensing the current and let to the wire resistance to limit the short-circuit current.
- Including a current limiting inductance in each tap, which reduces the short-circuit current, but enlarges the commutation process.

In this paper first method of zero crossing detector use for switching operation.
The layout of the prototype is as shown in figure 1.This prototype semiconductor tap changer consists of a thyristor as the switching device to turn on the selected tap of the power transformer. As displayed in figure 1, the low voltage circuit is separated from the high voltage circuit in order to protect the microcontroller from damage.
Furthermore, this step-down transformer helps in bringing down the transformer's output voltage to an appropriate value for microcontroller operation. This reduced voltage is then compared with reference voltage before fed into the triggering circuit. The output of the microcontroller is also connected to an isolator as mentioned earlier. There is a 115/12 V step-down transformer, peak detector, filter and pulse transformer forming a feedback loop circuit. The function of this feedback loop is to convert the 110 V AC line voltage at secondary of the tap-changing transformer to an acceptable DC level voltage for the microcontroller. Peak detector will detect the peak value of the feedback signal feedback signal and gives a constant DC equivalent voltage. While the pulse transformer acts as an electrical isolator to the input of microcontroller.

89S52 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 in to the microprocessor. The microcontroller act as a trigger by injecting pulses to the selected thyristor pair representing the appropriate taps. At any instant, only one pair of thyristor will be in its ON state while others are turned OFF.

No.	Quantity	Value
1	Number of phases	1(Single)
2	Transformer rating in (KVA)	1KVA
3	**Nominal regulated voltage at output side is**	**115V**
	If tapping 1 select at normal load O/P voltage is	125V
	If tapping 2 select at normal load O/P voltage is	120V
	If tapping 3 select at normal load O/P voltage is	115V
	If tapping 4 select at normal load O/P voltage is	110V
	If tapping 5 select at normal load O/P voltage is	105V
4	Rated input voltage (Volt)	230V
5	Number of voltage step	6
6	Voltage of every step at rated conditions (Volt)	5V, (rms)
7	Maximum output current (Ampere)	9.524 ≅ 10A, (rms)
8	Tapping provided at	**HV (High voltage) side**

Table.1 Details of prototype Transformer

III. CONTROL STAGE IMPLEMENTATION

There are number of microcontrollers available such as NMIT-0020 F68HC11,89c51, 89s51, 89s52 and 89s55. By using of suitable microcontroller, control to process the input signal and produce a suitable output signal according to the program loaded into the microprocessor. The microcontroller act as a trigger by injecting pulses to the selected SCR. In this proposed scheme 89s52 controller is used.

As shown in figure 2 five tapings are provided on the HV side of the transformer. These tapings are selected by anti parallel pair of thyristor which is the new topology presented in this project. For operating the appropriate thyristor pair required gate signal, which is supplied by the gate driver card. And gate driver cards are driven by microcontroller. Here as represented in figure master controller card do this job. Microcontroller takes this decision based on value of feedback signal coming from secondary of the transformer.

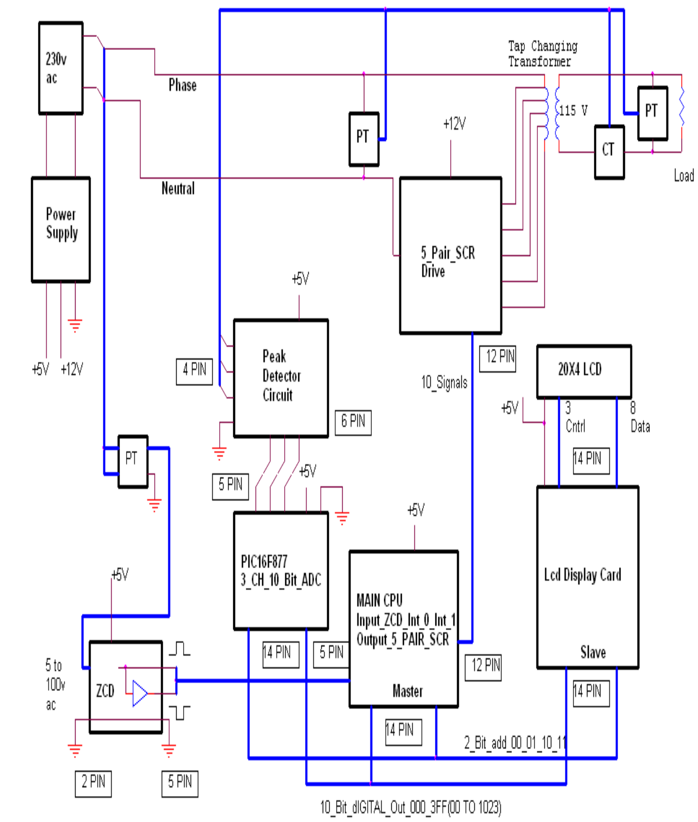

Fig. 2 Detailed control and power scheme

A signal coming from the secondary of the transformer is an analog signal so it is required to convert it into digital. A to D converter card is used to convert the signal into the digital form. Now signal is ready to get transferred into the microcontroller. Peak detector and ZCD card is also essential for microcontroller operation.

Two potential transformers are used as shown in figure 2, one for sensing the voltage from secondary and another for sensing the voltage at primary side of the transformer. Current transformer is used for sensing the current from secondary of the transformer. These sensing signals are fed to the microcontroller for taking the decision of tap change.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

In table 2 and 3 the testing results of regulation of the output voltage when load is increase or decrease is given. Here percentage regulation of transformer is 10%. The tap-changer controller regulates the output voltage ± 5 V of nominal voltage (115V).

LOAD IN AMPERE	CONDITION FOR uC	INPUT VOLTAGE	OUTPUT VOLTAGE	TAP NO.
0.5 A	Nominal	230 V	**115-116 V**	Tap 3 select
0.7 A	Nominal	230 V	113-114 V	Tap 3 select
0.9 A	Nominal	230 V	112-113 V	Tap 3 select
1.2 A	Load increase	230 V	110-111 V	Tap 3 select
1.4 A	Load increase	230 V	109-111 V	Tap 3 select
Microcontroller sense the output voltage and change the according tap for regulate the output voltage				
1.4 A	Regulate	230 V	**117-118 V**	Tap 5 select
1.8 A	Nominal	230 V	115-116 V	Tap 5 select
2 A	Nominal	230 V	**114-115 V**	Tap 5 select
1.8 A	Nominal	230 V	115-116 V	Tap 5 select
1.6 A	Nominal	230 V	118-119 V	Tap 5 select
1.4 A	Nominal	230 V	119-120	Tap 5 select
1.2 A	Load decrease	230 V	120-121	Tap 5 select
Microcontroller sense the output voltage and change the according tap for regulate the output voltage				
1.2 A	Regulate	230V	**111-112 V**	Tap 3 select
0.9 A	Nominal	230V	112-113 V	Tap 3 select
0.7 A	Nominal	230V	113-114 V	Tap 3 select
0.5 A	Nominal	230V	**114-115 V**	Tap 3 select

Table 2 Output voltage regulate when transformer load goes increase/decrease

LOAD IN AMPERE	CONDITION FOR uC	INPUT VOLTAGE	OUTPUT VOLTAGE	TAP NO.
0.5 A	Nominal	**230 V**	**114-115 V**	Tap 3 select
0.5 A	Nominal	228 V	113-114 V	Tap 3 select
0.5 A	Nominal	226 V	112-113 V	Tap 3 select
0.5 A	Nominal	224 V	111- 112 V	Tap 3 select
0.5 A	Nominal	222 V	110-111 V	Tap 3 select
0.5 A	Nominal	220 V	109- 110 V	Tap 3 select
0.5 A	I/P Voltage decrease	218 V	108- 109 V	Tap 3 select
Microcontroller sense the output voltage and change the according tap for regulate the output voltage				
0.5 A	Nominal	**218 V**	**113-114 V**	Tap 5 select
0.5 A	Nominal	216 V	112-113 V	Tap 5 select
0.5 A	**ALARM FOR UNDER VOLTAGE**	**214 V**	**111- 112 V**	Tap 5 select
0.5 A	Regulate	220 V	114-115	Tap 5 select
0.5 A	Nominal	222 V	115-116	Tap 5 select
0.5 A	Nominal	224 V	116-117	Tap 5 select
0.5 A	Nominal	226 V	118-119	Tap 5 select
0.5 A	I/P Voltage increase	228 V	119-120	Tap 5 select
Microcontroller sense the output voltage and change the according tap for regulate the output voltage				
0.5A	Regulate	**228 V**	**114-115 V**	Tap 3 select
0.5 A	Nominal	230 V	115-116 V	Tap 3 select
0.5 A	Nominal	232 V	116-117 V	Tap 3 select
0.5 A	Nominal	234 V	117-118 V	Tap 3 select
0.5 A	Nominal	236 V	118-119 V	Tap 3 select
0.5 A	I/P Voltage	238 V	119-120 V	Tap 3 select

Table 3 Output voltage regulate when supply voltage goes down/up

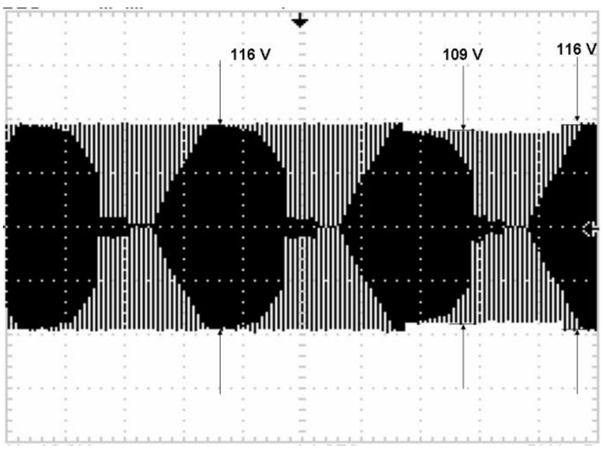

Fig.3 Switching on heavy load with microcontroller semiconductor tap-changer

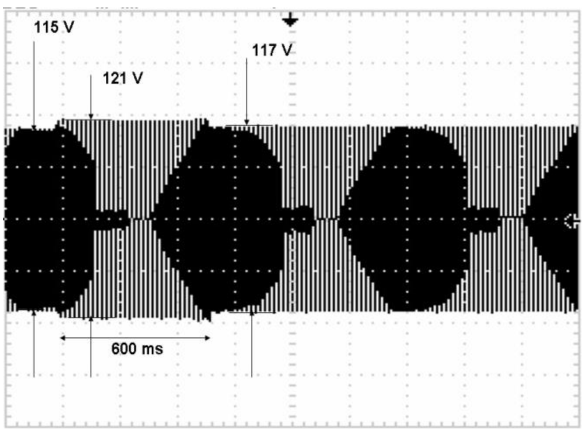

Fig.4 Load rejection with microcontroller semiconductor tap-changer

The above figure 4 shows the result of OLTC hardware with controller. Figure 4 shows the waveform when suddenly load is decreased with constant input. In this condition output voltage increases. But it should be regulated in certain range. And in this OLTC project microcontroller sense and change the transformer tap within millisecond and regulate the output voltage within a specified range. Here solid state switches are used hence fast switching is possible. Figure 3 displays the controlled waveform, when suddenly load is increased. So suddenly output voltage is decreased. The microcontroller senses this change and operate/fire the appropriate thyristors pair and select transformer tap.

V. CONCLUSION

Any variation at the output voltage of the distribution transformer will be sensed by the microcontroller and compare with the reference value as per the program. This will produce appropriate command to trigger the appropriate pair of anti parallel thyristors for change in the suitable tapping of transformer. The system stability is improved, because of quick response. Because of static devices, maintenance cost is reduced due to elimination of frequent sparking. Output voltage can be regulated in the range of ±5 V of nominal voltage.

VI. REFERENCES

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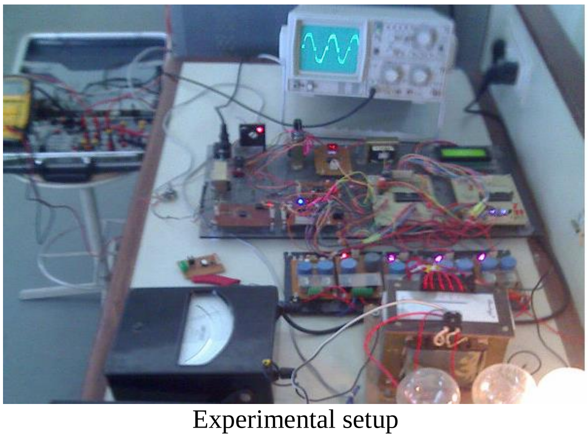
VII. APPENDIX



Experimental setup