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Voltage Regulation by Solid State Tap Change Mechanism for Distributing Transformer

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***Abstract*—Distributed Generation has gained its importance after considering the environmental hazards and recent developments in the renewable energy sector. The penetration of Distributed Generation and varying load at the consumer side has its own demerits of maintaining the constant output voltage at the consumer side. Since voltage is one of the most important parameter for the control of electric power system, hence it needs to be maintained atleast near to its constant value. The method involve in maintaining the output voltage within the acceptable limit at the consumer side is by Tap Changing mechanism associated with the distributing transformer. This project work deals with the replacement of conventional Electro-mechanical way of On-Load Tap changers with the Solid State Tap Changers for voltage regulation. With fully electronic control of tap changing the problems associated with the mechanical On-Load tap changing which includes excessive conduction losses, slow operation and arcing in the diverter switch have been properly rectified. It also explains the sequential switching of the Thyristor to regulate the voltage, based on the voltage feedback taken from the output side. Here Pulse Width Modulation (PWM) technique is adopted for sequential switching of the Thyristor, depending on the voltage feedback. By adopting Solid State tap changers in the distribution transformers fast and reliable operation is ensured and also encourages the proliferation of Distribution Generation.**

***Keywords*—On-Load Tap Changer, Pulse Width Modulation, Silicon Controlled Rectifier (SCR), pulse transformer.**

I.INTRODUCTION

Voltage is one of the most important parameter for the control of power systemA distribution transformer is a transformer that provides the final voltage transformation in the electric power distribution system, stepping down the voltage used in the distribution lines to the level used by the customer. A voltage regulator is designed to automatically maintain a constant voltage level.

A. Distribution Transformer

A distribution transformer is a transformer that provides the final voltage transformation in the electric power distribution system, stepping down the voltage used in the distribution lines to the level used by the customer. The invention of a practical efficient transformer made AC power distribution feasible.

B. Automatic Voltage Regulator

A voltage regulator is designed to automatically maintain a constant voltage level. A voltage regulator may be a simple "feed-forward" design or may include negative feedback control loops. It may use an electromechanical mechanism, or electronic components. Depending on the design, it may be used to regulate one or more AC or DC voltages.

C. Variable Shunt Reactor

Variable Shunt Reactors are used in high voltage energy transmission systems to stabilize the voltage during load variations. A traditional shunt reactor has a fixed rating and is either connected to the power line all the time or switched in and out depending on the load. The regulation speed is normally in the order seconds per step and around a minute from max to min rating. The VSR can continuously compensate reactive power as the load varies and thereby securing voltage stability.

D. Tap Changer

A tap changer is a connection point selection mechanism along a power transformer winding that allows a variable number of turns to be selected in discrete steps. A transformer with a variable turn’s ratio is produced, enabling stepped voltage regulation of the output. The tap selection may be made via an automatic or manual tap changer mechanism. Generally tap changers are classified into two types.

(i) Off-circuit or de-energized tap changing (DETC) is sometimes employed in high voltage transformer designs. Since the different tap points are at different voltages, the two connections cannot be made simultaneously, as this would short-circuit a number of turns in the winding and produce excessive circulating current. Consequently, the power to the device must be interrupted during the switchover event. It is only applicable to installations in which the loss of supply can be tolerated.

(ii) On-Load Tap Changer (OLTC) is employed for many power transformer applications, where supply interruption during a tap change is unacceptable. On-load tap changers may be generally classified as either mechanical, or electronically assisted, or fully electronic.

A mechanical tap changer physically makes the new connection before releasing the old using multiple tap selector switches, but avoids creating high circulating currents by using a diverter switch to temporarily place large diverter impedance in series with the short-circuited turns. This technique overcomes the problems with open or short circuit taps. In a typical diverter switch powerful springs are tensioned by allow power motor, and then rapidly released to affect the tap changing operation. To reduce arcing at the contacts, the tap changer operates in a chamber filled with insulating transformer oil, or inside an SF6vessel.

Thyristor-assisted tap changers use thyristors to take the on-load current while the main contacts change over from one tap to the previous. This prevents arcing on the main contacts and can lead to a longer service life between maintenance activities.

Solid State Tap Changers are typically employed only on smaller power transformers. Solid state tap changers which uses thyristors both to switch the load current and to pass the load current in the steady state.

E. Distributed Generation

The development of Distributed Generation in India has been quite impressive. Over the last few years, a number of influences have been combined to lead to the increased interest in the use of small-scale generation, connected to local distribution systems, which is commonly called 'Distributed Generation' (DG).The DG on the networks will make a significant reduction of the total consumption of fossil fuelled electricity, hence allowing a substantial minimisation of Carbon-di-oxide emission.

F. Overview of penetration of distributed generation

Control of Distributed Generation (DG) systems in power distribution systems is very important task that must be considered carefully. The presence of local generation in a distribution system will affect the distribution system. Distribution networks have not been designed to cope with power injections from DG, therefore the proliferation of DG on the electric networks results in a number of adverse effects. Typically, one the most severe situation is that voltage magnitude at the proximity of DG exceeds the statutory limits during maximum power output from DG and minimum power demand from the network. In such case the DG will alter the power flow in the distribution system, and the distribution system can no longer be considered as a system with unidirectional power flow. Here the network experiences the largest reverse power flow and large voltage change; hence the network has become active distribution network. An active distribution network is defined as distribution network with system in place to control a combination of distributed energy resource comprising of both generator and storage which affects the network safety and stability.

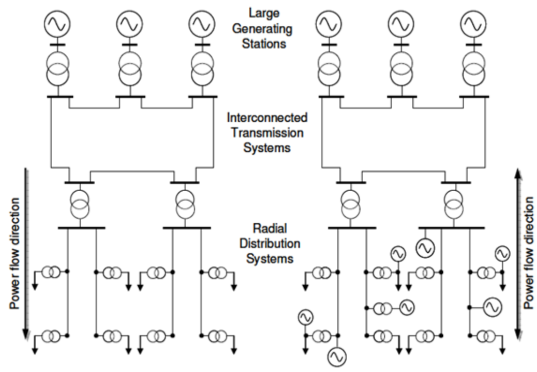

Fig. 1. Traditional electric power (left) and electric power system with distributed generations (right).

Voltage is one of the most important parameters for the control of electric power systems. Hence the voltage stability cannot be compromised. An easily implemented and cost-efficient method for grid integration of DG and regulating the voltage at consumer side is by improving the transformer control concept of MV/LV-transformer, which is typically an On-Load Tap Changing transformer control. The On-Load Tap Changer (OLTC) transformers are used between these multiple voltage levels to regulate and maintain the voltage which is supplied to consumers within statutory limits. The OLTC voltage regulation is naturally operated by changing the number of turns in one winding of the transformer to physically alter the ratios of the transformers.

Voltage regulation at the sub-transmission and distribution levels strongly relies on the use of transformer tap changers, implemented now-a-days by means of sophisticated electromechanical mechanisms. The possibility of replacing such slow and prone-to-wear switches by electronic devices has been the subject of much interest in the last few years.

G. Existing model

The conventional OLTC transformer adopts the mechanical on-load tap-changer. The major parts of the mechanical tap changer are on-off selector or tap-changer, diverter switch, transition resistance. A mechanical tap changer physically makes the new connection before releasing the old using multiple tap selector switches, but avoids creating high circulating currents by using a diverter switch to temporarily place large diverter impedance in series with the short-circuited turns. In a typical diverter switch powerful springs are tensioned by a low power motor (motor drive unit (MDU)), and then rapidly released to effect the tap changing operation. To reduce arcing at the contacts, the tap changer operates in a chamber filled with insulating transformer oil, or inside an SF6vessel.To prevent contamination of the tank oil and facilitate maintenance operations, the diverter switch usually operates in a separate compartment from the main transformer tank, and often the tap selector switches will be located in the compartment as well. All of the winding taps will then be routed into the tap changer compartment through a terminal array.

H. Problems in existing model

- The mechanical regulating tap-changer of the traditional OLTC transformer produces the electric arc in the tap changing process, and the tap-changer's movement speed is slow, the regulating response time is long.
- Mechanical drive components, brushes and contractors require regular maintenance and/or replacement.
- Frequent overloads can damage brushes.
- Speed of voltage correction correct may not be fast enough for electronic loads
- It has the high failure rate, maintains difficultly and is unable to accurately control regulating time.

So this kind of mechanical on-load tap changer has not been able to completely satisfy the security of the modern electrical network and the request of economical movement

I. Proposed model

Like the conventional electro-mechanical OLTC, the solid state tap changer also needs a transformer with several tapings. The solid state tap changer is connected in series to an MV or LV feeder. In addition to a common MV/LV transformer the solid state tap changer is an alternative to an conventional OLTC in the MV/LV transforming station. The solid state tap changer operates as follows:

In order to increase the voltage during a voltage drop on the output side, the equipment extracts voltage feedback via the Transformer. Through controlling the thyristor using Pulse Width Modulation (PWM) technique, the solid state tap changer regulates the voltage by changing the tap on the primary side of the transformer with the aim of obtaining a constant operating voltage on the output side according to the reference value. If there is a voltage increase in the output side, the solid state tap changer operates correspondingly. The solid state tap changer has several advantages compared to the conventional OLTC. The solid state tap changer regulates the voltage within milliseconds, while the conventional OLTC needs at least several seconds. Furthermore, the solid state tap changer is normally used with a timing relay to reduce the number of tap settings. The solid state tap changer regulates the voltage continuously, while the voltage is set in stages by the conventional OLTC. Furthermore, the solid state tap changer is able to regulate each single phase.

II. VOLTAGE STABILITY

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. It depends on the ability to maintain/restore equilibrium between load demand and load supply from the power system. Instability that may result occurs in the form of a progressive fall or rise of voltages of some buses. A possible outcome of voltage instability is loss of load in an area, or tripping of transmission lines and other elements by their protections leading to cascading outages that in turn may lead to loss of synchronism of some generators.

III. VOLTAGE CONTROL IN ELECTRIC DISTRIBUTION NETWORK

The voltage variation ΔV across the line can be approximated and represented by the following equation:

$$\Delta V = \frac{PR+QX}{V} \qquad (1)$$

Where ΔV indicates voltage variation, P and Q represent active and reactive power output of DG, X and R are reactance and resistance of the line connecting to DG, V is nominal voltage at the terminal of DG. An on-load tap changer (OLTC) transformer, a local load, a reactive power compensator, an automatic voltage controllers (AVCs), a line drop compensator (LDC) and a energy storage device are also connected on the network.

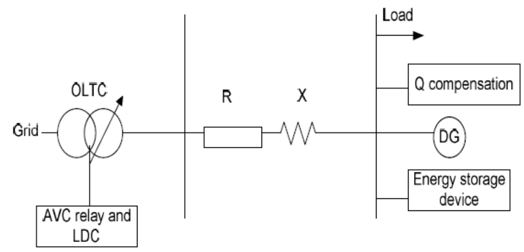

Fig. 2. Simple radial feeders with connected DG

Generally, compared with transmission line, the X/R ratio is relatively low in a distribution network. According to equation, any significant amount of power injected by DG will result in voltage rise/drop on the distribution network, especially in a weak distribution feeder with high impedance. The voltage variation would also depend on several factors including DG size and location, and method of voltage regulation.

A. Role of Oltc

The most common voltage control technique on the distribution network is to use OLTCs which maintain a stable secondary voltage by selecting the appropriate tap position. It is an effective way to control the voltage by shifting phase angle and adjusting voltage magnitude. It is usually in conjunction with AVC relay and LDC. The AVC relay continuously monitors the output voltage from the transformer; a tap change command will be initiated when the voltage is above the pre-set limits. The LDC is used to compensate additional voltage drop on the line between the transformer and load location, particular, in the far end of the feeder.

- In order to cope with dramatic changes on network management system, intelligent distributed controllers will be widespread on the network to minimise.
- The voltage impacts. The control structure will move from simple control strategy to two hierarchical level operations. The fundamental level is local level and the second level is coordinated level. The local voltage control aims to maintain voltage at DG units in a fast control response. The coordinated level considers a system wide perspective for voltage control of a distribution network.

B. Coordinated voltage and Reactive power control

The voltage and reactive power control in distribution systems has for many years been based on local operation of the OLTC and shunt capacitors. However in line with the mode mization of electricity distribution, coordinated voltage and reactive power control with short term operation planning has been adopted in to distribution systems. The OLTC is controlled by considering the dispatch schedule of all capacitors in order to reduce the number of OLTC operations.

IV. VOLTAGE CONTROL BY STATIC OLTC

A. Basic control mechanism

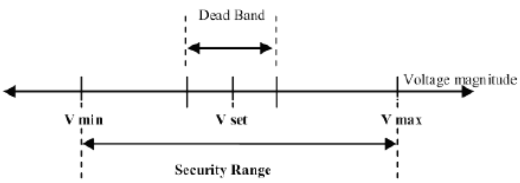

Fig. 3. Voltage Control representation

The control scheme of a conventional OLTC transformer is briefly explained in this chapter. Automatic OLTC controls within ±18% change of nominal voltage. The upper most tap represents -18% changes to nominal voltage, while lower most tap represents +18% changes. The **V**min refers to -18% and **V**max to +18%. OLTC transformer reduces the error in voltage till secondary voltage is within the dead band operating tap positions. Tap changing results step change in voltage.

The voltage in between two steps i.e., between two taps can be obtained through static/semiconductor tap changing systems with sequence control with voltage error less than ±0.1%.

The voltage at load end / secondary side of automatic OLTC transformer is measured and compared with the pre-set value. If the difference is within the dead band, no operation takes place and if the difference lies outside the dead band an appropriate lower or raise correction will start after a pre-determined delay. This process will be repeated until the secondary voltage is within the inner dead band. The main purpose of time delay is to prevent unnecessary tap operations due to temporary voltage fluctuations. Tap changing is done by switching Thyristor in respective taps. In addition to the above automatic tap control; a sequence control is introduced between taps for obtaining fine secondary voltage.

B. Sequence voltage control

An attempt is made to adjust output voltage by controlling Thyristors in between taps. The control of Thyristors is achieved through firing angle control. A typical output waveform using sequence modulation method.

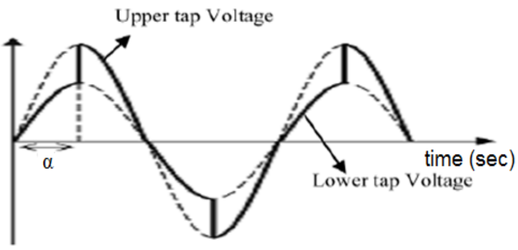

Fig. 4. Firing Angle Control of Voltage

In this method of control, output voltage can be represented as a function of α (firing angle), as given below

Vrms is f (α)

$$\sqrt{\frac{1}{\pi}\left\{\int_{0}^{\alpha} (\mathrm{Vlt}\sin(\omega t))^2\, d(\omega t) + \int_{\alpha}^{\pi} (\mathrm{Vup}\sin(\omega t))^2\, d(\omega t)\right\}} \qquad (2)$$

α - firing angle, Vlt - Peak Value of Lower taps voltage

Vup - Peak Value of Upper taps voltage

Vrms – Resultant rms value

Using above stated equation by varying the firing angle, voltage control in between taps can be obtained.

Condition: 1

Vref> Present selected Tap Voltage

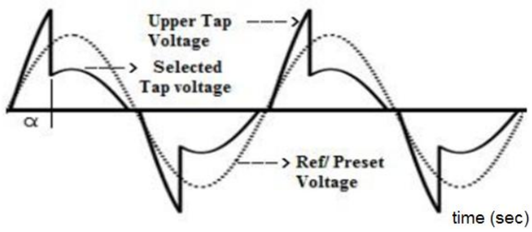

Fig. 5. Firing control between upper tap voltage & selected tap voltage

In this condition firing control is being performed between present selected tap and lower voltage tap, to reduce the voltage further to reach pre-set voltage.

Condition: 2

Vref< Present selected Tap Voltage

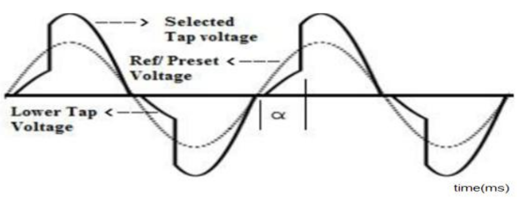

Fig. 6. Firing control between lower tap voltage & selected tap voltage

In this condition firing control is being performed between present selected tap and lower voltage tap, to reduce the voltage further to reach pre-set voltage.

V.BLOCK DIAGRAM DESCRIPTION

The proposed model consists of many blocks. Each and every block has its own features and applications

1. Full Wave Rectifier
2. LM324 (Operational Amplifier)
3. Flip flop
4. Timer
5. Counter
6. Decoder
7. Pulse Transformer
8. SCR Controlled Regulator
9. Voltage Regulator
10. SCR control board

Each of the blocks is individually and elaborately mentioned in this chapter. The proposed model consists of varying load but the output voltage is constant.

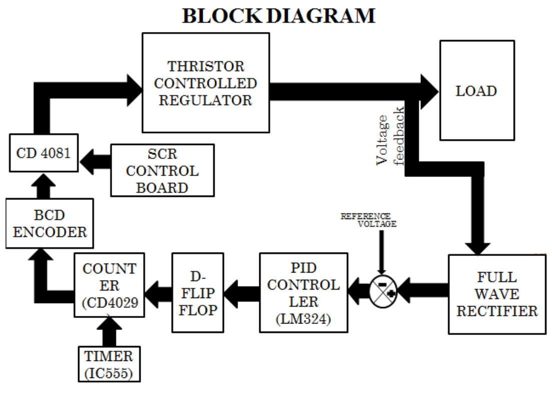

Fig. 7. Block diagram of the proposed system

A. *Pulse transformer*

Pulse transformer designers usually seek to minimize voltage droop, rise time, and pulse distortion. Droop is the decline of the output pulse voltage over the duration of one pulse. It is caused by the magnetizing current increasing during the time duration of the pulse. It is used to avoid core saturation and therefore needs to understand the voltage-time constant. Pulse Transformers are small in size and provide all the desirable qualities expected from the transformers designed to handle square pulses. The Magnetic flux in a typical AC transformer core alternates between positive and negative values. But the Magnetic flux in a pulse transformer does not. Pulse transformer operates in a unipolar mode.

B. *Voltage regulator*

Any Electrical or Electronic device that maintains the voltage of a power source within the acceptable limits. The voltage regulator is needed to keep the voltages within the prescribed range that can be tolerated by the electrical equipment using that voltage. Voltage Regulators used in Electronic equipment in which excessive variations in voltage would be determined.

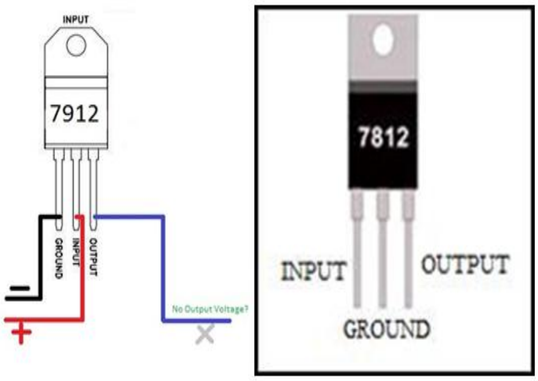

Fig. 8. Pin diagram of 7912 and 7812

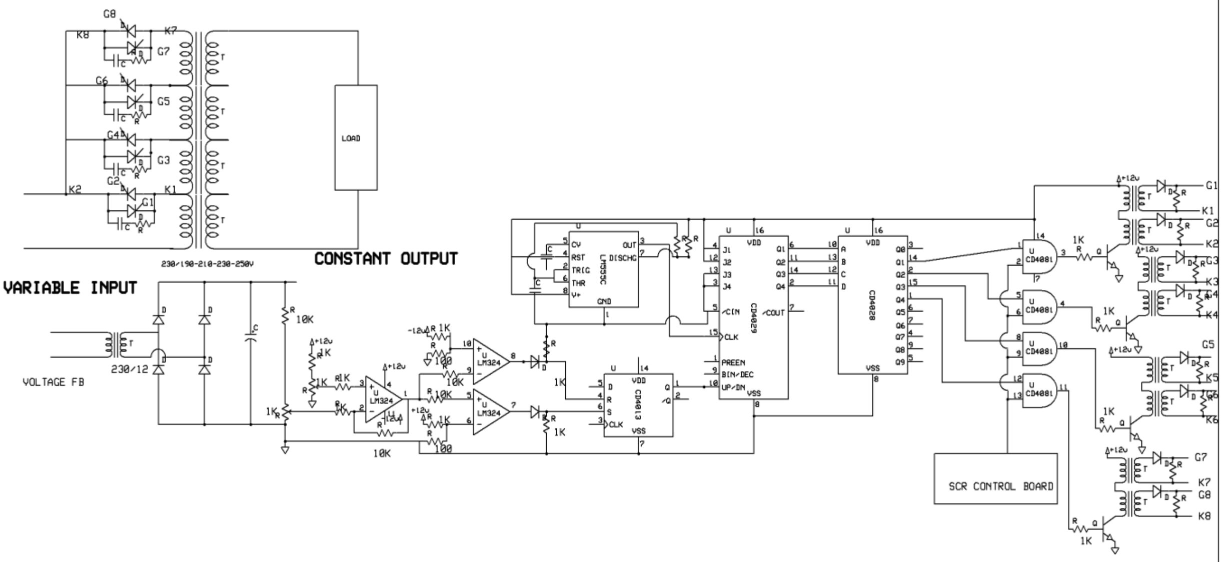

Fig. 9. Circuit Diagram of the Proposed Model.

In this project we are using 7812 as a positive regulator. The input may be 16V or even 20V, output will be 12V. Here the negative side is taken as common line, common to both input and output. 7912 is a negative regulator. You can derive -12 from -16 to -20V. The positive of the input is common to both input and output.

VI. CIRCUIT DESCRIPTION

The hardware of the proposed model consists of three taps on the winding of the transformer to regulate the voltage at the consumer side. The circuit diagram of the proposed model is briefly explained.

The power source is connected to the cathode K1 and K2 and anode G1 and G2 of the thyristor switch. Thyristor gets triggered and the voltage is fed to the load. The voltage feedback is taken from the lines feeding the load. Then voltage feedback is connected to the 230/12 V step down transformer followed by rectifier circuit with filter. Hence the output from the full wave rectifier will be smooth DC voltage. This DC voltage is compared with the reference voltage with the help of LM324 comparator. The error voltage from the comparator circuit is used to modulate the counter values. Depending upon counter value the pulse width is modulated, where the pulses are generated with the help of IC555 and the modulated pulse width output is taken from the JAM lines of the counter.

The output from the counter is binary; hence it is connected to the decoder which makes only one pin to HIGH at any time. So the corresponding AND gate connected to the output pin of the counter will be triggered. The modulated pulse signal is given to the pulse transformer to switch the thyristor to increase/decrease the tap based upon the voltage feedback to regulate the voltage on the consumer side.

VII.CIRCUIT OPERATION

The implementation of the hardware falls into two categories, it either increase the tap position or decrease the tap position depending upon the under load or overload condition. This can be briefly explained by the following two cases.

Case 1: Consider a case if the loads connected to the supply are suddenly switched off, the voltage of the lines feeding the loads will be increased; hence the voltage feedback gets increased. The feedback voltage is stepped down by 230/12 V transformer and fed to full wave rectifier. This causes the output from full wave rectifier to rise. This voltage is compared with the reference DC voltage by using a comparator LM324. The comparator produces negative error at the output of the comparator. This error is taken by the upper negative reference comparator to increase the gain of the error signal. This error signal forward biases the diode and fed to reset terminal of the flip flop. Because of the reset terminal gets triggered, output of the flip flop will be LOW. Hence the counter counts down. Clock pulses generated from the IC555 is given to the counter to count the number of clock pulses. The output of the counter will be binary output. It is then given to the input to the decoder. Only one pin of the decoder is enabled as HIGH. This high pulse waveform is connected to the one of the input of AND gate and the other input is connected from the timer IC555. So for each clock cycle at some period of time, the two inputs will be same. At that time the pulse wave form is generated at the output of the AND gate and is given to the pulse transformer. Pulse transformer generates pulses to trigger the gate of the thyristor and then the tap gets decreased to maintain the constant output voltage.

Case 2: Consider a case if the loads connected to the supply are suddenly increased, the voltage of the lines feeding the loads will be decreased; hence the voltage feedback gets decreased. The feedback voltage is stepped down by 230/12 V transformer and fed to full wave rectifier. This causes the output from full wave rectifier to lower. This voltage is compared with the reference DC voltage by using a comparator LM324. The comparator produces positive error at the output of the comparator. This error is taken by the lower positive reference comparator to increase the gain of the error signal. This error signal forward biases the diode and fed to set terminal of the flip flop. Because of the set terminal gets triggered, output of the flip flop will be HIGH. Hence the counter counts up. Clock pulses generated from the IC555 is given to the counter to count the number of clock pulses. The output of the counter will be binary output. It is then given to the input to the decoder. Only one pin of the decoder is enabled as HIGH. This high pulse waveform is connected to the one of the input of AND gate and the other input is connected from the timer IC555. So for each clock cycle at some period of time, the two inputs will be same. At that time the pulse wave form is generated at the output of the AND gate and is given to the pulse transformer. Pulse transformer generates pulses to trigger the gate of the thyristor and then the tap gets increased to maintain the constant output voltage.

A. *Scr Controlled Regulator*

A Thyristor (silicon controlled rectifier or SCR) is a little like a transistor. It consists of four layers of silicon in a p–n–p–n structure. Its circuit symbol shows that it is basically a diode, but with an additional terminal, called the GATE. The purpose of the gate is to enable the device to be switched from a non-conducting (forward blocking) mode into a low resistance, forward conducting state. Thus a small current applied to the gate is able to switch a much larger current (at a much higher voltage) applied between anode and cathode. Once the thyristor is conducting however, the gate current may be removed and the device will remain in a conducting state.

To turn the thyristor off, the current flowing between anode and cathode must be reduced below a certain critical "holding current" value, (near to zero); alternatively the anode and cathode may be reverse biased. The thyristor is normally made to conduct by applying a gating pulse, while the main anode and cathode terminals are forward biased. When the device is reverse biased the gating pulse has no effect.

VIII. SIMULATION RESULTS

SIMULATION MODEL

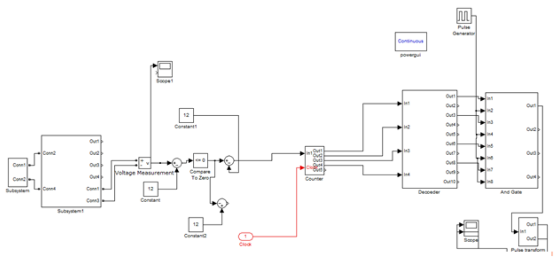

Fig. 10. Simulation Model Using MATLAB.

OUTPUT

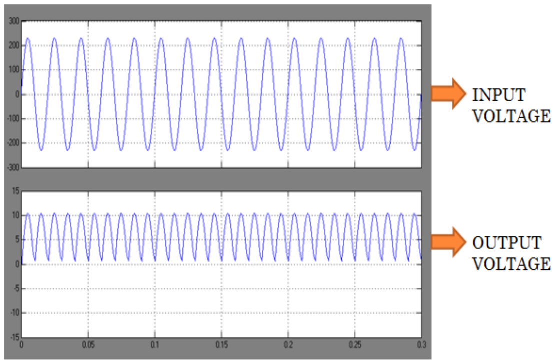

Fig. 11. Simulation Of Output Voltage.

COMPLETE SYSTEM OUTPUT

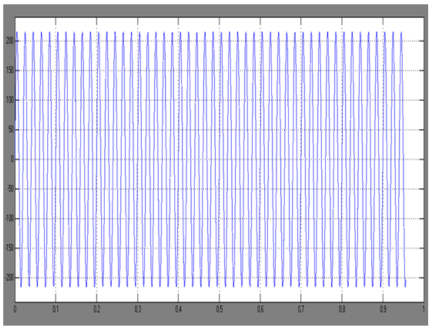

Fig. 12. Complete System Output (Output Side To Maintain the Constant Output Voltage)

IX. CONCLUSION

The way distributed networks are operated now-a-days is properly conditioned by the need to keep the voltage magnitude within the acceptable limits especially at the LV levels on penetration of the Distributed Generation. This requirement is achieved by Mechanical tap changers. Power Electronic semiconductor switches which are becoming cheaper and more reliable, hence offer better opportunities to provide added control flexibility. In this project solid state tap changer employing thyristor switch control with 3 tap positions is proposed to regulate the voltage at the consumer side depending on the voltage feedback taken from the load side. Pulse Width Modulation (PWM) technique is adopted for sequential switching of the thyristor.

X. FUTURE ENHANCEMENT

The magnitude of output voltage which needs to be maintained constant cannot be altered in the proposed model. But it is possible by changing the reference point. Changing the reference point in the proposed model is not possible because of the technical difficulties. A fuzzy algorithm can be adopted to provide an adaptive reference of the OLTC controller which can mitigate the effect of the high penetration of the DG units. The motivations behind using the fuzzy logic are:

- It can map nonlinear relations behind its inputs and output.
- It can provide a smooth transition, which lead to a more relaxed tap operation.
- It requires less remote data measurements compared to the centralized approaches.

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