Journal of Engineering and Applied Sciences 14 (10): 3383-3389, 2019
ISSN: 1816-949X

Implementation of a Fuzzy Logic Based FC-TCR (SVC) to Maintain Voltage Stability for Microgrid

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Abstract: In order to improve transmission capacity and maintain transmission flexibility, we use FACTS technology based entirely on power electronics. Fixed capacitor thyristor control reactor compensation technology is a shunt-type FACTS control technology used in power systems to maintain steady-state voltage stability in power system networks. The demand for electricity as an economic source of energy is growing rapidly. Therefore, renewable energy sources are being widely used. Renewable energy systems are important to meet the growing demand for energy systems engineers have introduced solar energy into the grid. The injection of renewable source stations has caused problems. Therefore, the power quality of the power line does not meet the standards. This study consists of a fuzzy logic-based Fixed-Capacitance Thyristor Control Reactor (FC-TCR) controller for improving voltage stability. This study introduces the use of a fuzzy system with rapid control features on the basis of the continuous compensation method. In the field of power engineering, the design and simulate fuzzy logic control of FC-TCR and trigger angles to achieve better, smoother voltages. Using a Fixed Capacitor Thyristor Controlled Reactor (FC-TCR) is advantageous because it can increase dynamic stability, load transmission line capabilities and the quality of electricity. Simulation results indicate the effectiveness of the proposed compensation strategy in improving the quality of electricity and the stability of system.

Key words: Power quality, renewable energy sources, FC-TCR, micro grid, smart grid, technology

INTRODUCTION

Power quality is very important for all levels of electricity users. Sensitive instruments and non-linear loads are common in both domestic and industrial environments. In order to keep the terminal voltage at the load bus sufficient, a reaction reserve is required. Facts devices such as the SVC type FC-TCR can provide or absorb reactive power at the load side bus of the transmission line which helps to obtain better power transmission economy (Dugan *et al*., 1996).

The demand for electric power is continuously increasing. To meet this demand, the entire energy system is operated at its maximum capacity, thereby potentially generating problems of stability, voltage collapse and network failure. Controllers of flexible AC transmission systems are used to improve the stability and security of power systems along with their main application of power flow control for end users and efficiently use the available transfer capabilities. Compensating reactive power through a Static VAR Compensator (SVC) leads to the following benefits: a high level of voltage in the busbar:

- Reduction of energy losses
- Reduction of consumption
- Improvement of the power factor
- Efficient use of existing power plants
- Low plant losses

Traditional energy is often used to generate electricity. Typical sources of such energy are fossil fuels including oil, natural gas and coal. Generation capacity must be increased and loss should be reduced to meet the increasing power demand and optimise the transfer of energy at different levels (Liserre *et al*., 2011). Thus, far, traditional energy sources play an important role in generating electricity. However, engineers are now attempting to find alternative energy sources to address the increasing demand for electricity while reducing the pressure on the availability of conventional energy because of the negative environmental impacts such as greenhouse gas emissions and detrimental effects on animals and plants, of traditional energy sources (Vishwakarma and Saxena, 2013).

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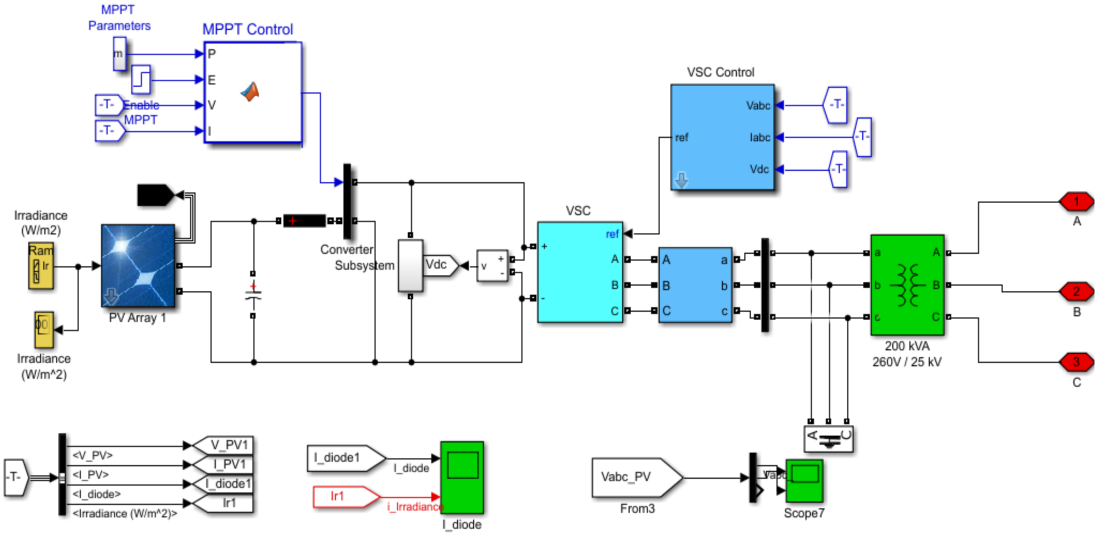


Fig. 1: Solar photovoltaic system; MPPT controllers using “Perturb and Observe” technique

The search for alternative energy has led engineers to discover renewable energy sources. The wind and solar energy are new renewable energy sources that provide backup energy for electricity generation and rural (off-grid) energy services. However, these renewable energy sources are more expensive than conventional ones and their long-term availability is uncertain. These shortcomings open up new areas of engineering and research with the goal of identifying the most cost-effective energy sources. As users of energy, we are responsible for realising such objective and promoting the use of alternative power (Wessels *et al*., 2013; Boynuegri *et al*., 2012).

MATERIALS AND METHODS

Solar Photovoltaic (PV) cell: At present, we rely mostly on non-renewable energy which continues to be an important cause of pollution and other types of natural corruption. Finding viable alternatives is increasingly important as a result of the reduction in oil supply. The best plan for a reasonable future, depending on the incorporation and control of renewable energies in the generation of energy. Like hydroelectric and wind power, Photovoltaic solar energy (PV) is the most important source of renewable energy in terms of universal introduction capabilities (Wessels *et al*., 2011).

Photovoltaic solar systems use solar panels to convert solar energy into electricity (Fig. 1). These solar panels contain photovoltaic cells. Photovoltaic cells are composed of semiconductor materials that show PV impact. The effect of PV is a phenomenon in which electrons are excited in a high-energy state using photons. These photons cause electrons to function as current carriers for the current. From a mathematical point of view (Fig. 2), the output current of a PV module can be displayed as (Agrawal and Bhuria, 2013):

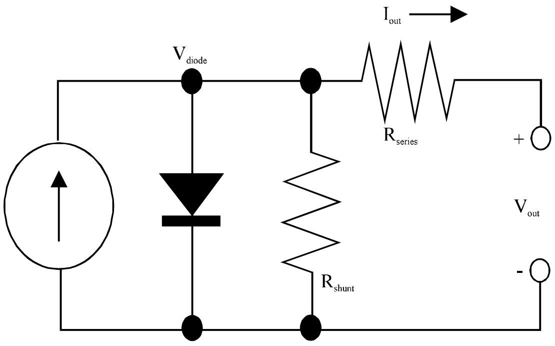


Fig. 2: Electrical circuit of PV cell

$$I = n_p I_{pv} - n_p I_o \left[\exp\left(\frac{V+IR_s}{aV_t}\right) \right] - \frac{V+IR_s}{R_p} \qquad (1)$$

Where:

I = Current
V = Voltage of the PV module
I_{pv} = Photocurrent
I_o = Reverse saturation current
n_p = Number of cells connected in parallel
n_s = Number of cells connected in series

Static VAR Compensator (SVC): Static VAR systems are used in transmission systems for various applications. The main function is the rapid control of the voltage in a transmission network. The device can be installed in the

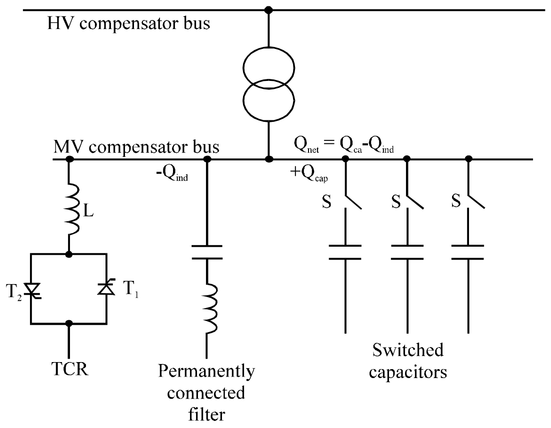


Fig. 3: Fixed capacitor thyristor-controlled reactor

middle or end sections of transmission lines. SVCs are static generators/absorbers connected in shunt that can be changed to control system voltage (Agrawal and Bhuria, 2013).

SVCs can improve transmission and distribution performance in many ways. Providing SVCs in one or more locations in a network can increase transmission capacity, reduce losses, maintain an even voltage profile in various operating situations, improve the dynamic stability of the system and soften fluctuations in active power (Ortiz *et al*., 2011).

SVCs are high-voltage systems that dynamically control network voltage at their coupling points. The main task of an SVC is to keep the network voltage constant on the basbar of a set reference value. An SVC usually consists of a Thyristor-Controlled Reactor (TCR) parallel to a bank of capacitors. From an operational point of view, SVCs behave like a shunt-connected variable reactance that generates or absorbs reactive power to adjust the voltage at points connected to the AC network (Fig. 3) (Bangia *et al*., 2013).

The bank of fixed capacitors is connected in shunt with the TCR to extend the controllable range to the main power factor region. The TCR MVAr has a greater capacity than the fixed capacitor to compensate for the capacitive MVAr and provide inductive reactive net power if a lagged power factor operation is desired. PF is defined as the ratio of kW-kVA extracted by the load where kW describes the real power flowing to the load and kVA mentions the apparent power of the circuit. The reactive power in the AC power system is the phase angle between the current and voltage waveforms. This is a reason for a low PF. This small PF increases loads of energy consumption and also leads to equipment damage. It is efficient to maintain the ideal value of PF near the unit to avoid losses and improve the efficiency of the source. The operational flow of the methodology to improve the FP is shown in Fig. 4. If PF = 1 it means that the waveform of the current is in perfect synchronization with the voltage waveform, so, the full power it is transferred to the load (Sahu, 2013).

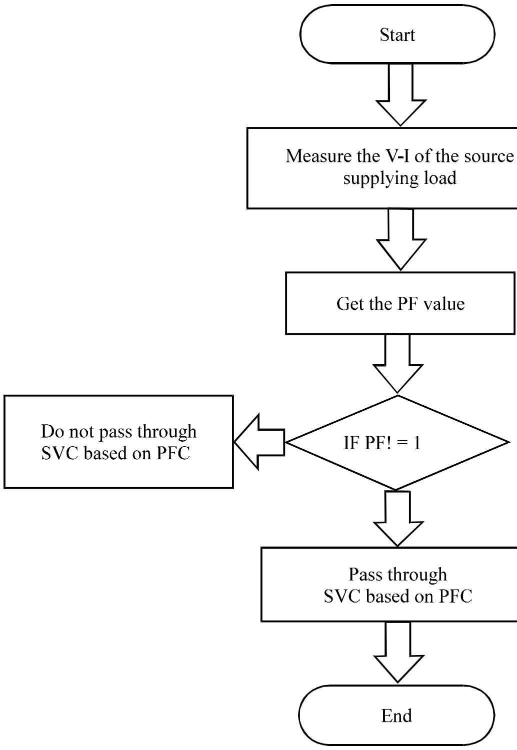


Fig. 4: Operational flow of PFC methodology

Control concept of SVC: The SVC control strategy has been studied in terms of enhancing dynamic and transient stability, improving disturbance transmission capacity and damping power oscillation. The concept of SVC control is based on the susceptance (B) of the control which can be controlled by modifying the thyristor's working angle. The objective of the SVC control is to maintain the desired voltage on the high voltage bus. In constant mode, SVC provides a fixed level of fixed voltage control to keep the high voltage bus at a predetermined level. If the load suddenly increases, the high-voltage bus will begin to drop to the specified value. In this case, the SVC injects the reactive power (Q_{net}), thereby increases the bus voltage and returns it to the desired voltage level. If the load drops suddenly, the voltage increases and the SVC (TCR) absorbs the reactive power. Consequently, the required bus voltage is reached (Vishwakarma and Saxena, 2013).

As shown in Fig. 3, $+Q_{cap}$ is a fixed capacity value. Therefore, the value of the reactive power that is fed into the system is controlled by the amount Q_{ind} power absorbed by the TCR. The SVC system is simulated with a Fixed-Capacity Thyristor Control Reactor (FC-TCR). The TCR can be varied by the variable resonance BSVC. The equivalent of the bequ susceptance can be determined by the α firing angle of the thyristor (Agrawal and Bhuria, 2013):

$$B_{EQU} = B_L(\alpha)+B_C \qquad (2)$$

Where:

$$B_L(\alpha) = \frac{1}{\omega L}(1-\frac{2\alpha}{\pi}-\frac{1}{\pi}\text{In}(2\alpha)) \qquad (3)$$

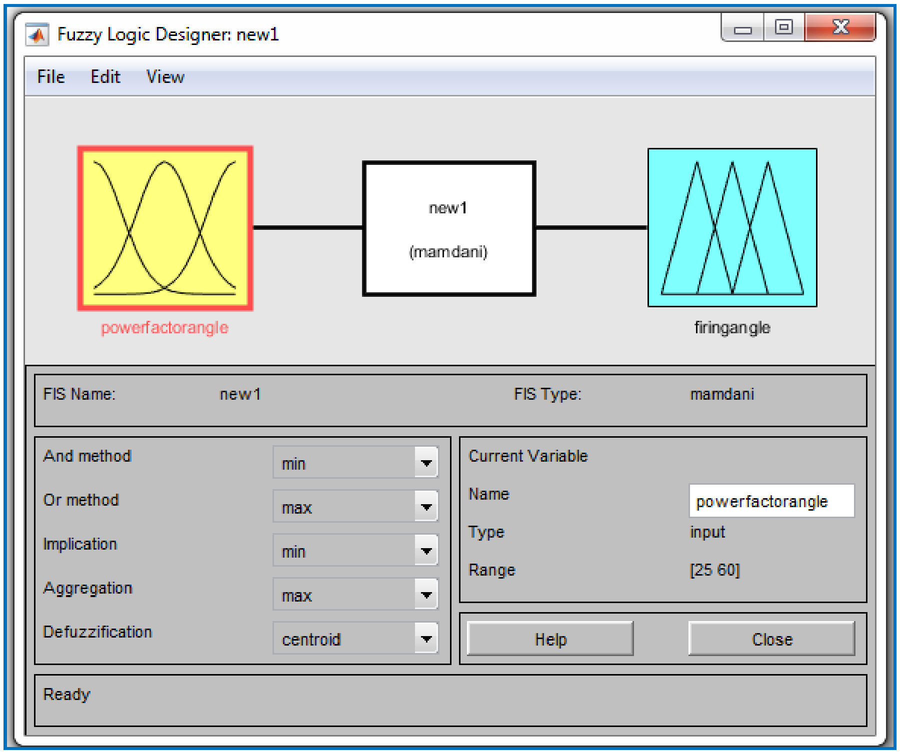
B_C = ωc and α varies from 0-90° If the real power consumed by the SVC is zero, then, $P_{SVC} = 0$:

$$Q_{SVC} = V^2 B_{SVC} \qquad (4)$$

where, V is the Value of the bus voltage.

Fuzzy logic interfacing: Fuzzy logic is an important part of artificial intelligence where algorithms are designed to mimic human thinking (Agrawal and Bhuria, 2013; Sahu, 2013). It also makes perfectly valuable decisions. Fuzzy logic interprets statements that are not clear to provide meaning. The process necessary for the system to work is stored in a fuzzy system. The diffuse primary system. The model accepts the input and the information is processed producing the output. The main function of the fuzzy logic controller includes the conversion of the input data to a fuzzy form called fuzzification. The fuzzification process is followed by processing according to the rules framed if then. Finally, the fuzzy output is converted into actual output data and the process is referred to as defuzzification. All system parameters must be properly evaluated when choosing the input and output membership functions and the decision rules must be configured to produce the required result. The fuzzy logic controller provides the firing angle obtained from the angle PF of the load to FC-TCR.

The power factor parameters are corrected based on the fuzzy logic mamdani rule. Complex power is obtained from the power measurement block with the power angle being the input to the fuzzy controller. The output (firing angle) is controlled by the power angle and is provided by the fuzzy controller. When the power angle is large, the firing angle is large. The control output is fed to the variable delay circuit and the thyristor. According to the output of the variable delay circuit, the firing angle of the thyristor is changed. When the power angle is good, the firing angle is fine. When the power angle is moderate, the firing angle is moderate. When the power angle is large, the firing angle is large (Fig. 5 and 6).



FIS Name: new1

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: centroid

Current Variable

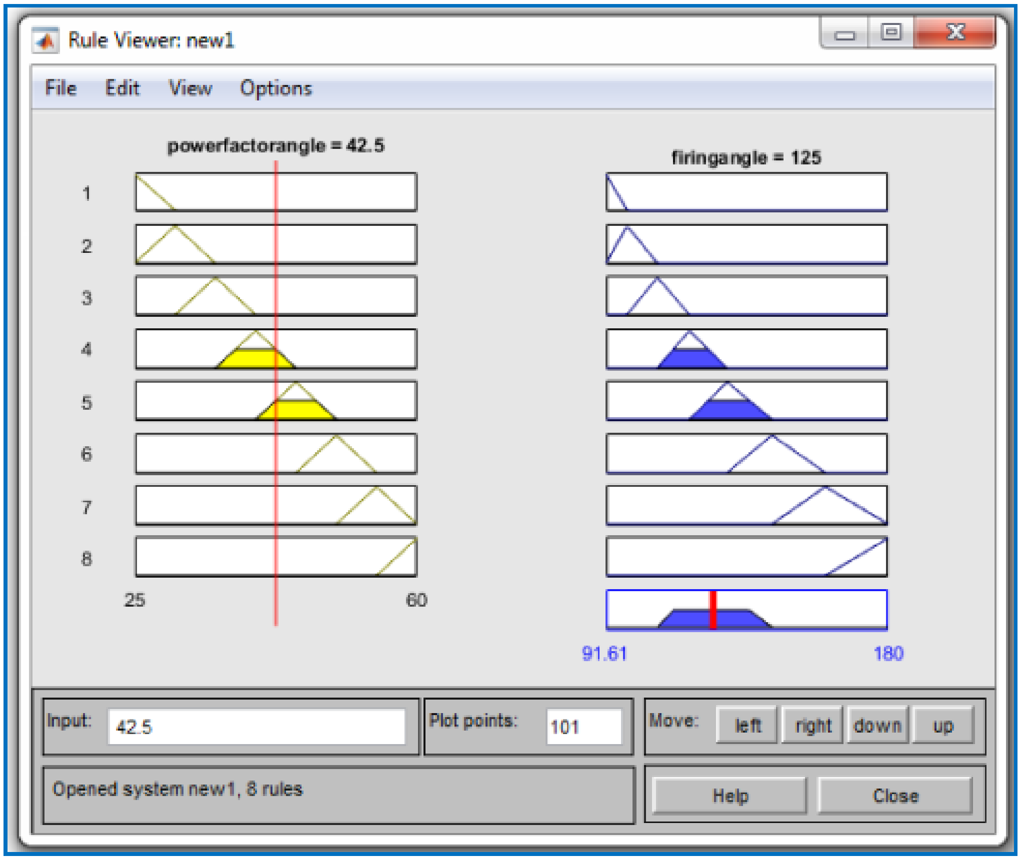
Name: powerfactorangle

Type: input

Range: [25 60]

Ready

Fig. 5: Membership function plot for input variable



Input: 42.5

Plot points: 101

Opened system new1, 8 rules

Fig. 6: Rule viewers for fuzzy controller

RESULTS AND DISCUSSION

Simulation model and results: In this simulation, FC-TCR is used as a compensation device and its excess amount of reactive power is absorbed by the reactor. Further, the detail controlling of the reactor in the simulation is addressed by the firing angle control of thyristor. The simulation is performed for a system with RLC load connected to the line supplied by the source. This load is connected to the source using a step signal that is used as enabling signal to connect or disconnect the load. The load chosen is highly inductive. Then we make use of designed PFC circuit and evaluate the design. This PFC circuit can be connected or disabled by setting the value of step signal. In this study, the FC-TCR circuit is connected to a PV system. MATLAB Simulation is performed for various inductive loads. Figure 7 shows the V-I characteristics and functioning of the FC-TCR area. The maximum inductive and capacitive admission are achieved by the voltage and rated current of the main components.

This study proposes a strategy that applies FC-TCR, excluding the compensator in a renewable energy-fed grid.

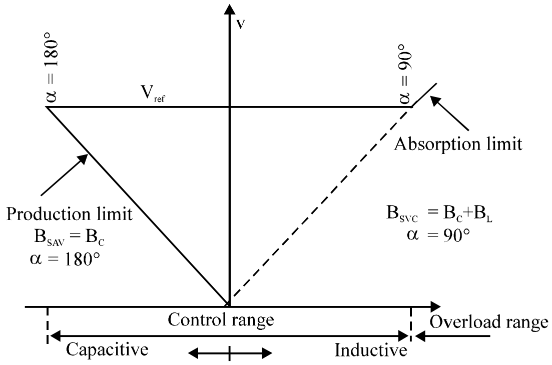


Fig. 7: Operating characteristics of FC-TCR

The grid has a PV machine and different sources which are linked by transmission lines. The accurate tracing and compensating capacitive current automatically (Fig. 8 and 9). Figure 10 and 11 show the arrangement of the PV array with FC-TCR. The PV array is designed according to its characteristic equation. Therefore, the boost converter is used to raise the voltage to the desired value.

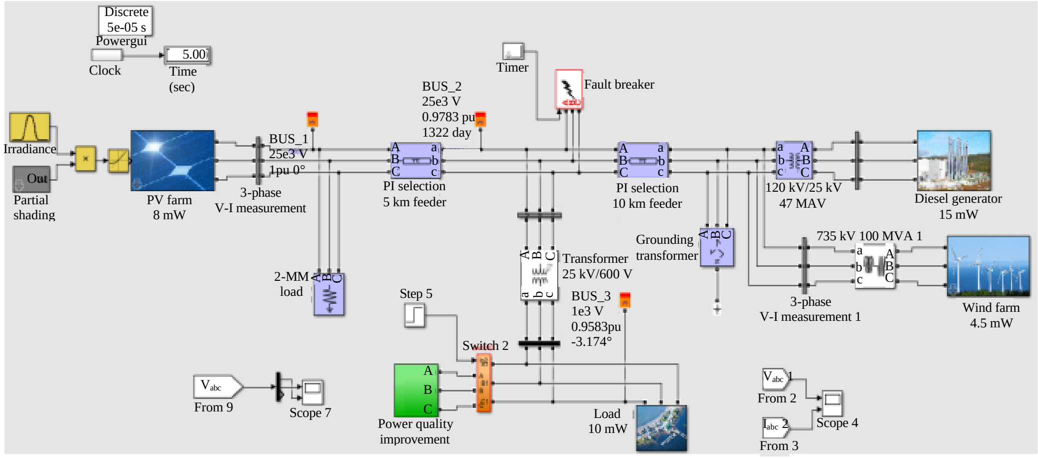


Fig. 8: Simulation model of distribution system with fuzzy logic controlled FC-TCR

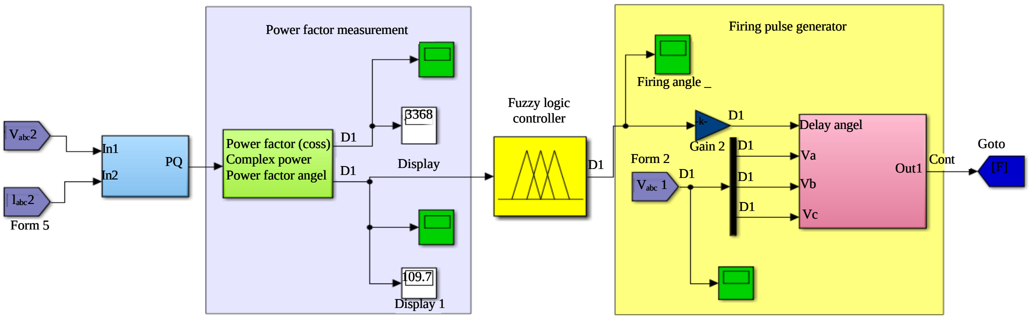


Fig. 9: Design of FC-TCR

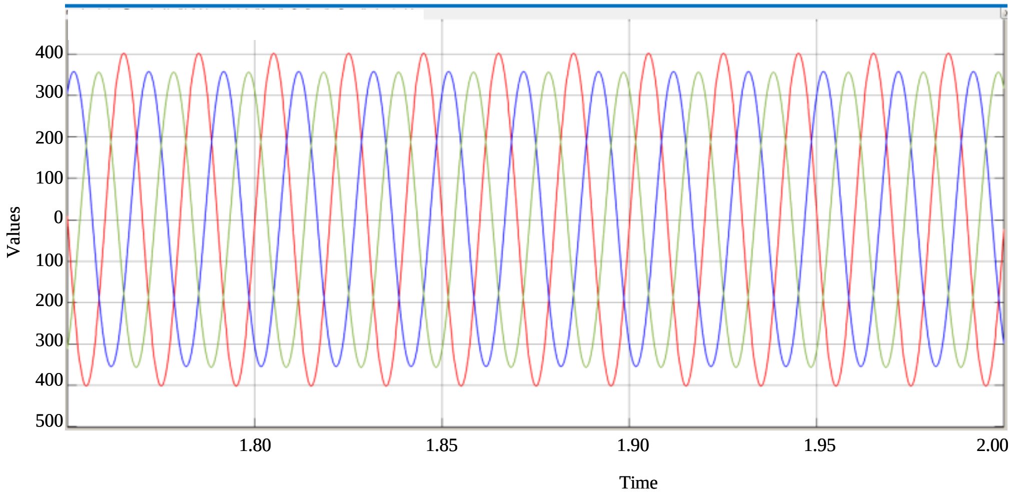


Fig. 10: Instantaneous voltage without any compensation; Data may be missing. Try unchecking "limit data points to last" from the configuration properties logging tab

To obtain the output, we connect the output of the inverter to the 100 kVA transformer. The feeder size is 10 km. To provide reactive power compensation, we design the FC-TCR and connect it to the grid. We then design the assist switch with a transformer to analyse the impact of FC-TCR.

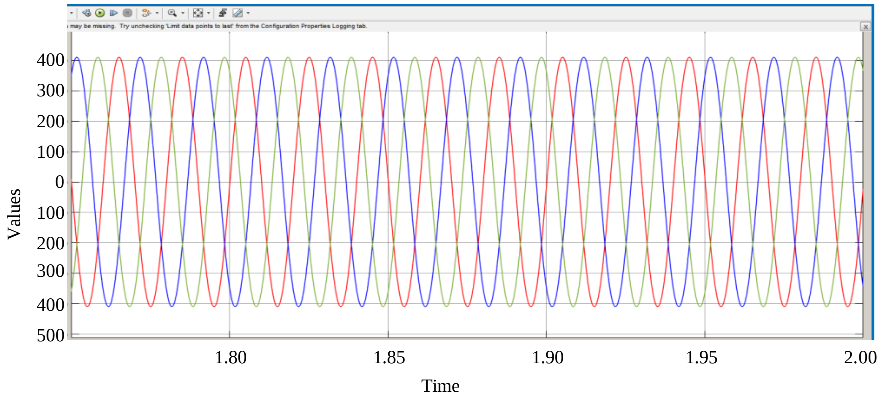


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Fig. 11: Instantaneous voltage after compensation

CONCLUSION

This study proposes a "Fuzzy control scheme for FC-TCR" which can be concluded as follows: fuzzy control with trigger angle control FC TCR compensation device it is continuous and effective and is the simplest method to control reactive power for transmission system. It has been observed that FC-TCR devices are capable of compensating the voltage. The basic use of fuzzy logic provides closed-loop control of the system and the rules are designing to set the firing angle to the FC-TCR to achieve the desired voltage.

Results of the simulation show a good fuzzy controller performance in the power factor correction and the reactive power of compensation. It is noted that, the FC-TCR device is able to compensate for both over and under voltage. The FC-TCR with a fuzzy controller is able to maintain a constant power factor at the end of the transmission line under abnormal conditions and the changes in load show no effect. The FC-TCR is also a cost-effective solution for maintaining constant voltage and power under load changes. An analysis of FFT with non-linear load can reduce harmonics to the desired limit. In MATLAB modelling, the SVC (FC-TCR) provides an effective control of reactive power regardless of load variation and offers voltage stability.

ACKNOWLEDGEMENT

We would like to express our deep gratitude to our dear advisers, Ms. Janan Al-Hajji and Dr. Shaorong Wang for motivating and inspiring us as, we completed this research work.

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