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ORIGINAL RESEARCH ARTICLE

AC-DC SOLID-STATE CONVERSION AND POWER FACTOR CORRECTION USING THYRISTOR-BASED STATIC VAR COMPENSATOR

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ABSTRACT

This paper presents AC-DC solid states converters with thyristor-based static Var compensator in power factor correction. There is need for solid-state ac–dc converters to improve power quality in terms of power factor correction, reduce total harmonic distortion at input ac mains and precisely regulate dc output. AC-DC converters operating in continuous-conduction mode have become popular because of reduced electromagnetic interference levels resulting from their utilization. The method employs the principle of interleaved converters, as it can be extended to a generic number of legs per winding of the autotransformers and high-power levels. The practical analysis of the converter is then plotted using a Simulink model of Matlab while a comparison of power factor and efficiency with relative to the load is drawn with Steady-State and Dynamic Performance of the Static Var Compensator (SVC). An experimental prototype load varied between 400W to 1 KW is implemented to validate the work. The results obtained indicates that when the output loads were 53KW, 135KW, 270KW, 470KW and 900KW, the efficiency were 55%, 70%, 80%, 90% and 97% respectively. These results confirmed that there was improvement in the power factor and efficiency with increase in the load.

1.0 Introduction

In the modern era, almost every household electronics works on Direct Current (DC) but we get Alternating Current (AC) from power generation plants via transmission lines because AC can be transmitted more efficiently than DC at lower cost. So every appliance which works on DC has an AC to DC converter circuit. AC is the dominant method of transporting power because it offers several advantages over DC, including lower distribution costs and simple way of converting between voltage levels as a result of invention of the transformer. AC power that is sent at high voltage over long distances and then converted down to a lower voltage is a more efficient and safer source of power in homes. Depending on the location, high voltage can range from 4KV up to 765KV. AC mains in homes range from 110V to 250V, depending on which part of the world you live (Alexander and Sadiku, 2013).

Conventionally, AC–DC converters, popularly referred to as rectifiers, are implemented using diodes and thyristors to provide uncontrolled, semi controlled and controlled dc power with unidirectional and bidirectional power flow (Miller and Abrahams, 2018). Reduction of harmonic content with the consequent increase of PF can be obtained by using either passive or active PF Correction (PFC) techniques. Passive methods include the use of tuned LC filters (Azazi et al., 2010).

Moreover, the passive filter may not respond adequately if the load PF comes to vary. On the other hand, active methods come as a more efficient solution by using controlled solid-state switches in association with passive elements such as resistors, inductors, and capacitors (Molinas and Garces, 2012). In fact, the closed-loop operation of a static power converter dedicated to PFC assures satisfactory performance with high input PF and regulated dc output voltage over a wide operating range. Increased complexity and reduced robustness are distinct characteristics of this practice. In order to meet the requirement standards such as IEC 61000-3-2, Das et al. (2011) and IEEE Standard 519, Glinka and Marquardt (2005) on the quality of the input current that can be drawn by low-power equipment, a PFC circuit is typically added as a front-end stage.

1.1 Rectifiers

Rectifiers are mainly classified into three types, namely Half-wave rectifier, Center tapped full-wave rectifier and Bridge rectifier. We observed that none of the three rectifier types can efficiently convert the Alternating Current (AC) into Direct Current (DC) but only the center tapped full-wave rectifier and bridge rectifier can efficiently convert the Alternating Current (AC) into Direct Current (DC). Figure 1 shows the block diagram of AC-DC converter with PFC.

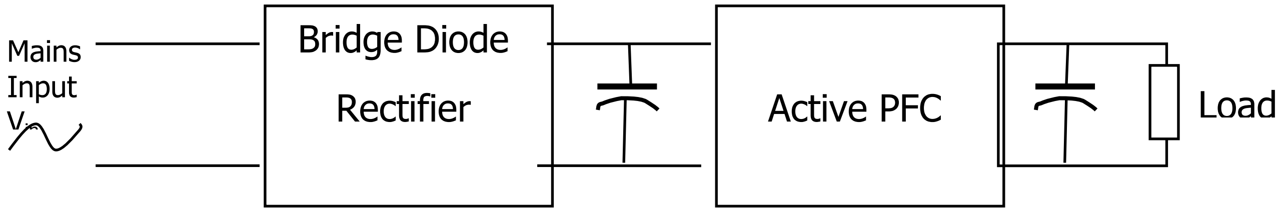

Figure 1: Block Diagram of AC-DC Converter with PFC

1.2 Power Factor Correction (PFC)

This refers to the method of increasing power factor (PF) by using active electronic circuits with feedback that control the shape of the drawn current. There are many commercial PFC controllers that can accomplish this task. In conventional non-PFC AC-DC power supplies a large filter capacitor (Co) is placed directly after bridge rectifier. Figure 2 shows the circuit diagram of forward converter using PFC control.

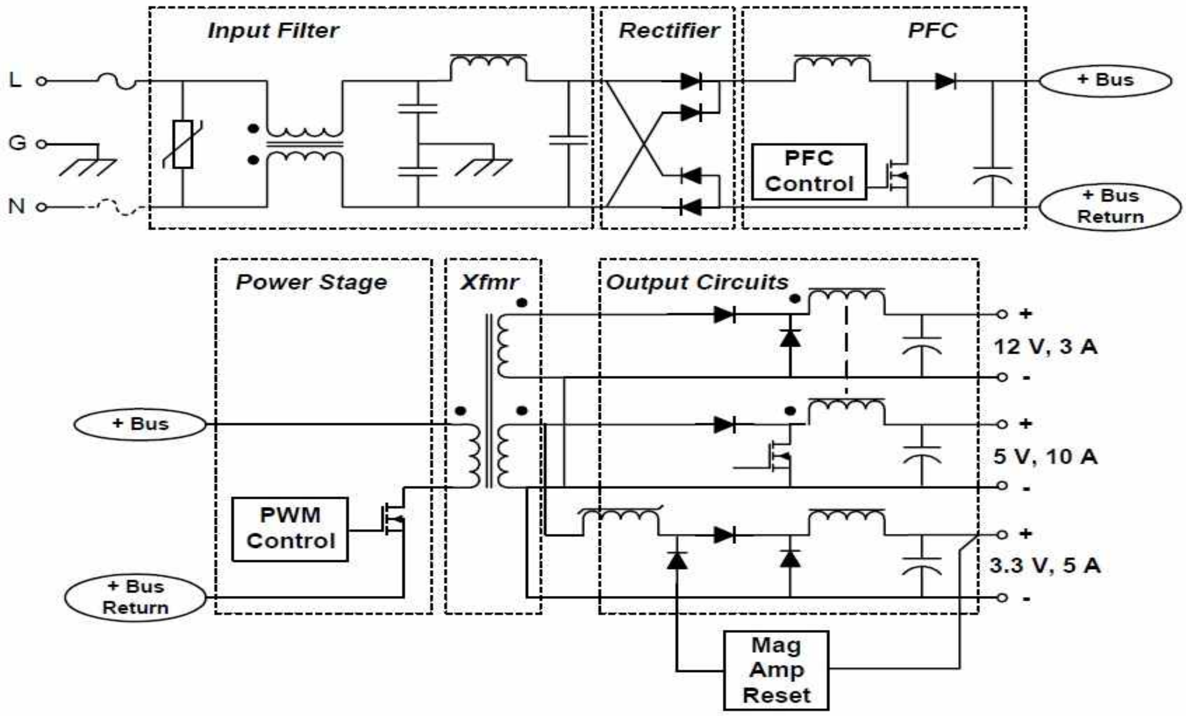

Figure 2: Circuit Diagram of Forward Converter using PFC Control

The unregulated input voltage with a constant magnitude is converted into a desired output voltage by fast switching using a MOSFET and the switching frequency is around 100 kHz. This unregulated DC voltage is fed to the large-filter capacitor or PFC (Power Factor Correction) circuits for correction of power factor as it is affected. This is because around voltage peaks, the rectifier draws short current pulses having significantly high-frequency energy which affects the power factor to reduce. It is almost similar to DC to DC converter but instead of direct DC power supply AC input is used. So, the combination of the rectifier and filter shown in Figure 1 is used for converting the AC into DC and switching is done by using a power MOSFET amplifier with which very high gain can be achieved, (Jeong, 2014).

The MOSFET transistor has low on-resistance and can withstand high currents. The switching frequency is chosen such that it must be kept inaudible to normal human beings (mostly above 20KHz) and switching action is controlled by a feedback utilizing the Pulse Width Modulation (PWM) oscillator, (Sedra and Smith, 2004). The stepping down of the voltage is done without a transformer as shown in Figure 3.

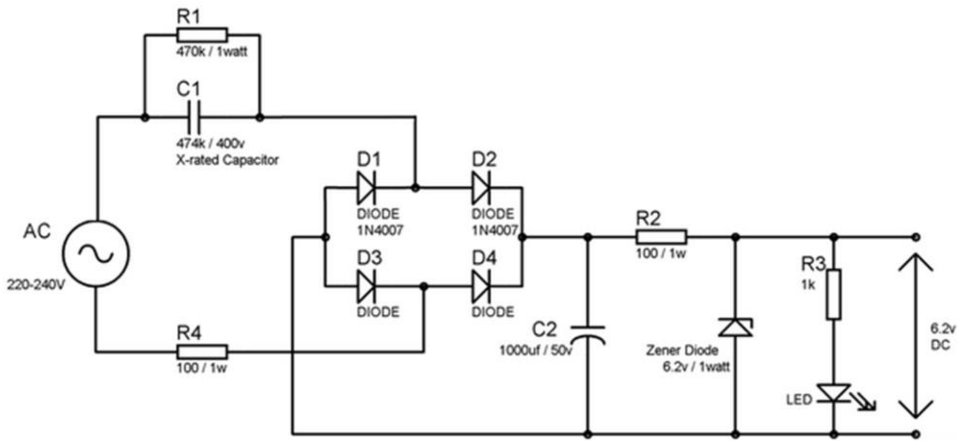

Figure 3: Conversion of an AC to DC and Stepping down the Voltage without Transformer

In Figure 3, the voltage dropping capacitor of 0.47uF is connected in series with phase line of AC, this is a non-polarized capacitors so it can be connected from any side. A 470KΩ resistor is connected in parallel of Capacitor to discharge the stored current in the capacitor when circuit is switched off, thus preventing from electric shock. This resistance is called Bleeder resistance and then, bridge rectifier has been used to remove the negative half component of AC. This process is called the Rectification, and 1000uF/50V capacitor has been used for Filtration, thereby removing the ripples in the waveform.

1.3 Input Filtering Block

An input filter is important as it prevents noise produced in the power supply switching elements from getting back onto the mains power supply. It also prevents noise that may be on the mains power supply getting into subsequent circuits. The filter passes through 50/60Hz mains frequency and attenuates higher frequency noise and harmonics that might be present. As with other parts of an AC to DC converter, reactive elements like capacitors and inductors perform the important role of frequency selective suppression. Capacitors do not pass DC, and can be used in series or parallel, (Levy, 2016).

1.4 Rectification

Rectifiers are implemented using semiconductor devices that conditionally conduct current in one direction only like diodes. More sophisticated semiconductor rectifiers include thyristors. Silicon Controlled Rectifiers (SCR) and Triode (TRIAC) for alternating current are analogous to a relay where a small amount of voltage can control the flow of a larger voltage and current. The way this work is that they only conduct when a controlling 'gate' is triggered by an input signal (Loffe and Regel, 2017).

By switching the device on or off at the right time as the AC waveform flows current is steered to create a DC separation. There are many circuits for doing this, with signals tapped off, the AC waveform used as control signals that set the phase quadrants thyristors are on or off. This is *commutation*, and can be either *natural* (in the case of a simple diode) or *forced*, as in the case of devices that are more sophisticated (Sedra and Smith, 2004).

Diodes have an intrinsic voltage drop across them when they conduct. This causes power to be dissipated in them, but other active elements may have much lower drop and therefore lower power loss. SCR and TRIAC circuits are particularly common in low cost power control circuits like the light dimmer, (Kittel, 2016).

The statement of problem of this paper is for a d.c load to receive the desired voltage and current ratings with reduced transformer and inductor sizes. Therefore A.C mains must be rectified and filtered to feed the power factor correction stage. The objective is to implement AC – DC conversion and power factor correction using solid state devices.

2.0 Materials and Method

The materials used in this paper include thyristor-based static Var compensator, A 735 kV/16 kV, 333 MVA coupling transformer, one 109 MVar TCR bank and three 94 MVar TSC banks (TSC1 TSC2 TSC3) connected on the secondary side of the transformer.

The SVC is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics. It regulates voltage by generating or absorbing reactive power.

Switching the TSCs in and out allows a discrete variation of the secondary reactive power from zero to 282 MVar capacitive (at 16 kV) by steps of 94 MVar, whereas phase control of the TCR allows a continuous variation from zero to 109 MVar inductive. Taking into account the leakage reactance of the transformer (0.15 pu), the SVC equivalent susceptance seen from the primary side was varied continuously from -1.04 pu/100 MVA (fully inductive) to +3.23 pu/100 MVar (fully capacitive).

The SVC Controller monitors the primary voltage and sends appropriate pulses to the 24 thyristors (6 thyristors per three-phase bank) to obtain the susceptance required by the voltage regulator. Figure 4 shows the single- line diagram of a static var compensator.

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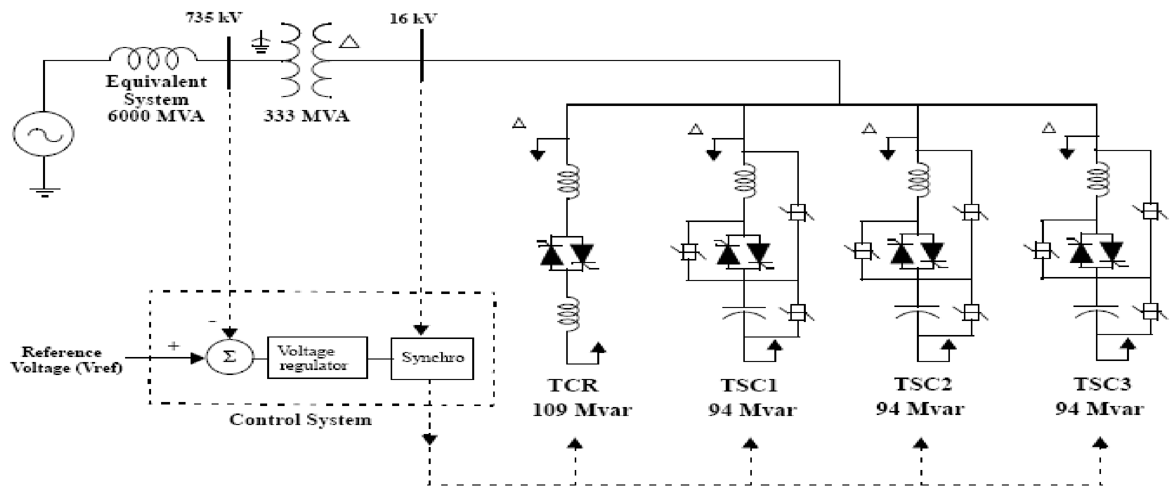

Figure 4: Single-line Diagram of a Static Var Compensator and Its Control System

The SVC regulates voltage at its terminals by controlling the amount of reactive power absorbed from the power system. When system voltage was low, the SVC generates reactive power (SVC capacitive). When system voltage was high, it absorbed reactive power (SVC inductive). The variation of reactive power was performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank was switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors were either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR). Figure 5 shows the selective problem solving (SPS) model of the 300MVar.

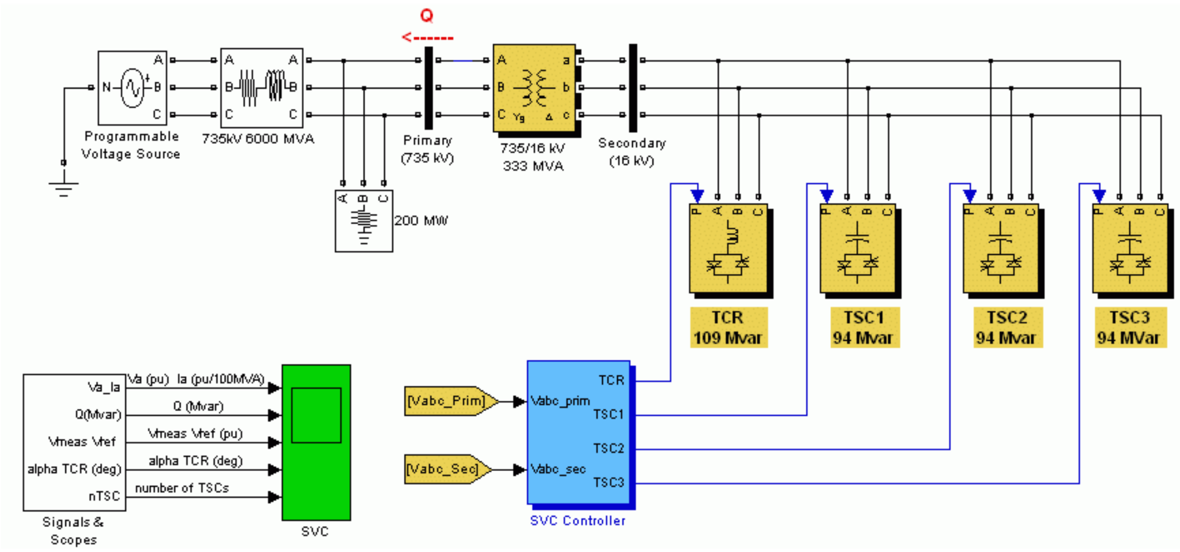

Figure 5: SPS Model of the 300 Mvar SVC

Switching the TSCs in and out allows a discrete variation of the secondary reactive power from zero to 282 Mvar capacitive at 16 kV by steps of 94 Mvar, whereas phase control of the TCR allows a continuous variation from zero to 109 Mvar inductive. Taking into account the leakage reactance of the transformer (0.15 pu), the SVC equivalent susceptance seen from the primary side was varied continuously from -1.04 pu/100 MVA (fully inductive) to +3.23 pu/100 Mvar (fully capacitive).

The SVC Controller monitors the primary voltage and sends appropriate pulses to the 24 thyristors (6 thyristors per three-phase bank) to obtain the susceptance required by the voltage regulator**.** Figure 6 shows the Simulink models of SVC controller.

The power system was represented by an inductive equivalent (6000 MVA short circuit level) and a 200-MW load. The internal voltage of the equivalent system was varied by means of a Three-Phase Programmable Voltage Source block to observe the SVC dynamic response to changes in system voltage, (Levy, 2016).

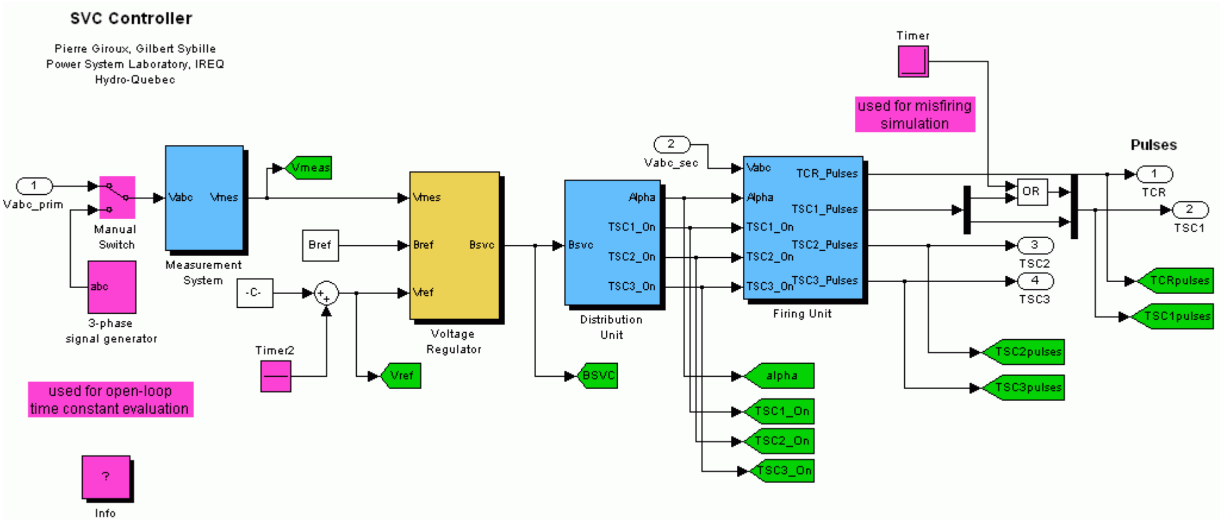

Figure 6: Simulink Models of SVC Controller

3.0 Results and Discussion

3.1 Steady-State and Dynamic Performance of the SVC

The steady-state waveforms and the SVC dynamic response when the system voltage was varied is shown in Figure 7.

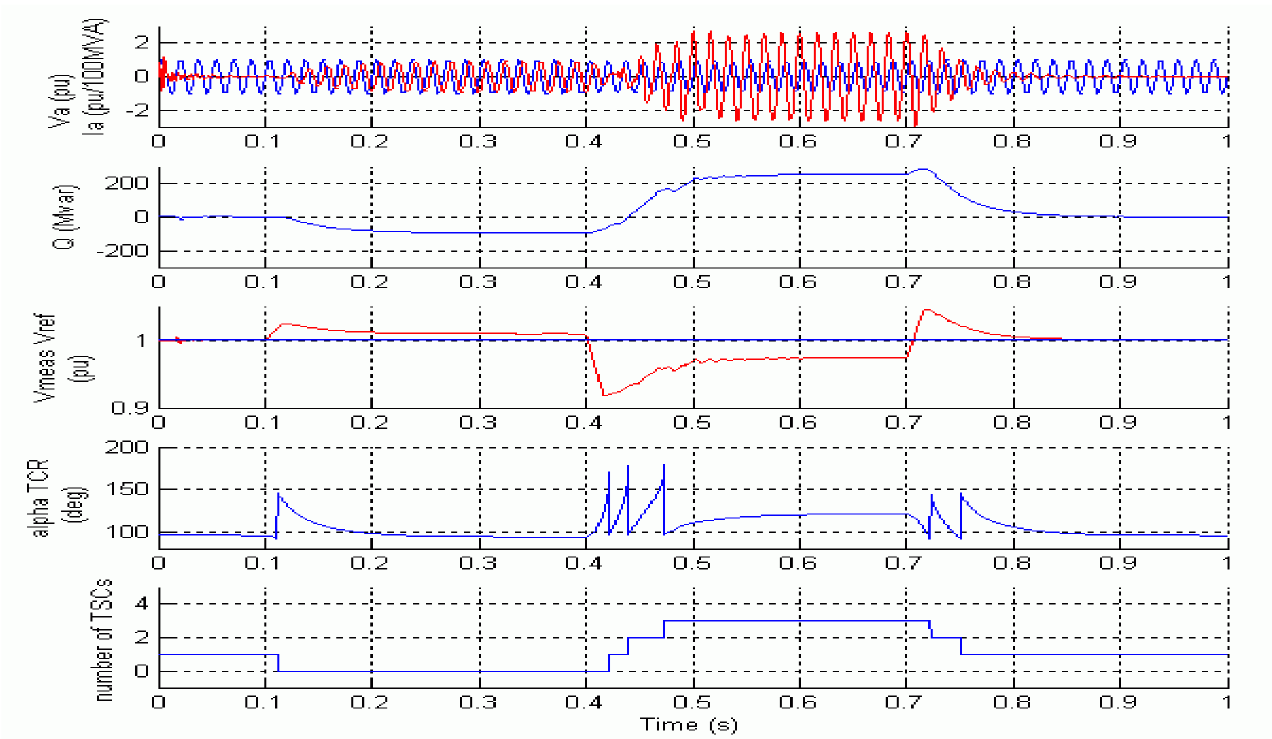

Figure 7: Waveforms Illustrating SVC Dynamic Response to System Voltage Steps

Initially, the source voltage was set at 1.004 pu resulting in a 1.0 pu voltage at SVC terminals when the SVC is out of service. As the reference voltage Vref is set to 1.0 pu, the SVC is initially floating. This operating point is obtained with TSC1 in service and TCR almost at full conduction (α = 96 degrees).

At t = 0.1s voltage is suddenly increased to 1.025 pu. the SVC reacts by absorbing reactive power (Q = -95 Mvar) to bring the voltage back to 1.01 pu. The 95% settling time is approximately 135 ms. At this point all TSCs are out of service and the TCR is almost at full conduction (α = 94 degrees).

At t = 0.4 s the source voltage is suddenly lowered to 0.93 pu. The SVC reacts by generating 256 Mvar of reactive power, thus increasing the voltage to 0.974 pu.

At this point the three TSCs are in service and the TCR absorbs approximately 40% of its nominal reactive power (α =120 degrees). We observe that on the last trace of the scope how the TSCs are sequentially switched on and off. Each time a TSC is switched on the TCR α angle changes from 180 degrees to 90 degrees. Finally, at t = 0.7 s the voltage is increased to 1.0 pu and the SVC reactive power is reduced to zero.

Also we can open the Signal and Scopes subsystem to observe additional waveforms. The TCR voltage and current in branch AB as well as thyristors pulses are displayed on the TCR AB scope. Figure 8 shows the zooms on three cycles when the firing angle α is 120 degrees.

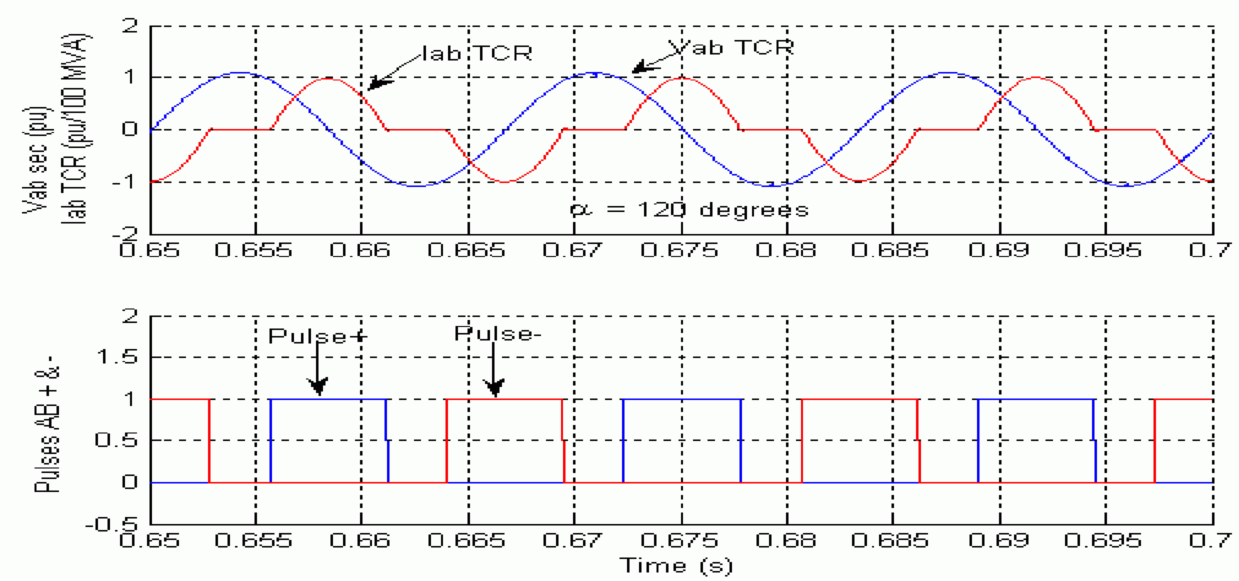

Figure 8: Steady-State Voltage and Current in TCR AB

3.2 Misfiring of TSC1

At the final stage, we simulated a TSC misfiring. Each time a TSC is switched off, a voltage remains trapped across the TSC capacitors. When looking at the TSC1 Misfiring scope inside the Signals and Scope subsystem, we can observe the TSC1 voltage and the TSC1 current for branch AB. The voltage across the positive thyristor (thyristor conducting the positive current) is shown on the third trace and the pulses sent to this thyristor are shown on the fourth trace. Again we noticed that the positive thyristor is fired at maximum negative TSC voltage, when the valve voltage is minimum.

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If by mistake the firing pulse is not sent at the right time, very large over currents can be observed in the TSC valves. By looking inside the SVC Controller block to know how a misfiring can be simulated on TSC1. A Timer block and an OR block is used to add pulses to the normal pulses coming from the Firing Unit.

By Opening the Timer block menu and removing the 100-multiplication factor. The timer is now programmed to send a misfiring pulse lasting one sample time at time t= 0.121 s.

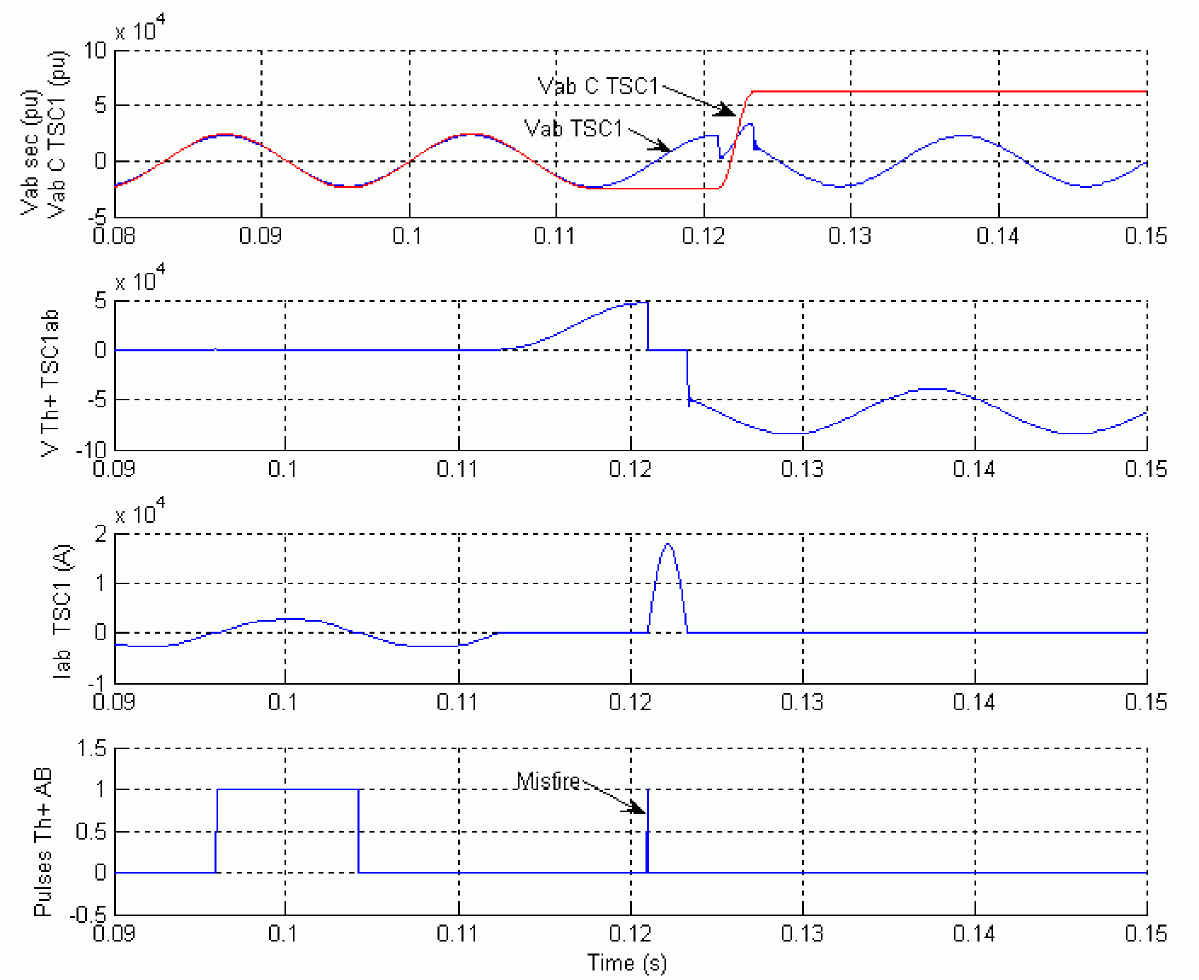

Figure 9: TSC Voltages and Current Resulting from Misfiring on TSC1

Table1: Power Factor results used for implementing hardware buck converter for various load conditions.

O/P load (W)	I/P Volt (V)	I/P Amp (A)	O/P Volt (V)	O/P Amp (A)	PF	Efficiency Wo/Wi
53	234	0.4	133	0.4	0.676	54.77
135	234	0.8	133	1.0	0.778	69.73
270	234	1.4	133	2.0	0.864	79.69
470	234	2.2	133	3.5	0.917	89.03
900	235	3.9	133	6.7	0.954	96.52

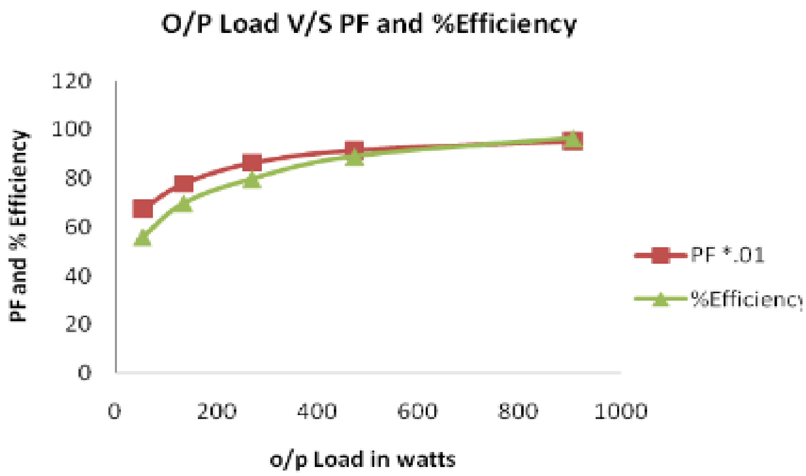

Figure 10: Power Factor and % efficiency V/S output load in watt

In the output result, we observed improvement in the power factor and efficiency as the load increases with zero crossing of currents and voltages and the waveform of crystal frequency of microcontroller output are 55%, 70%, 90% and on 97% respectively.

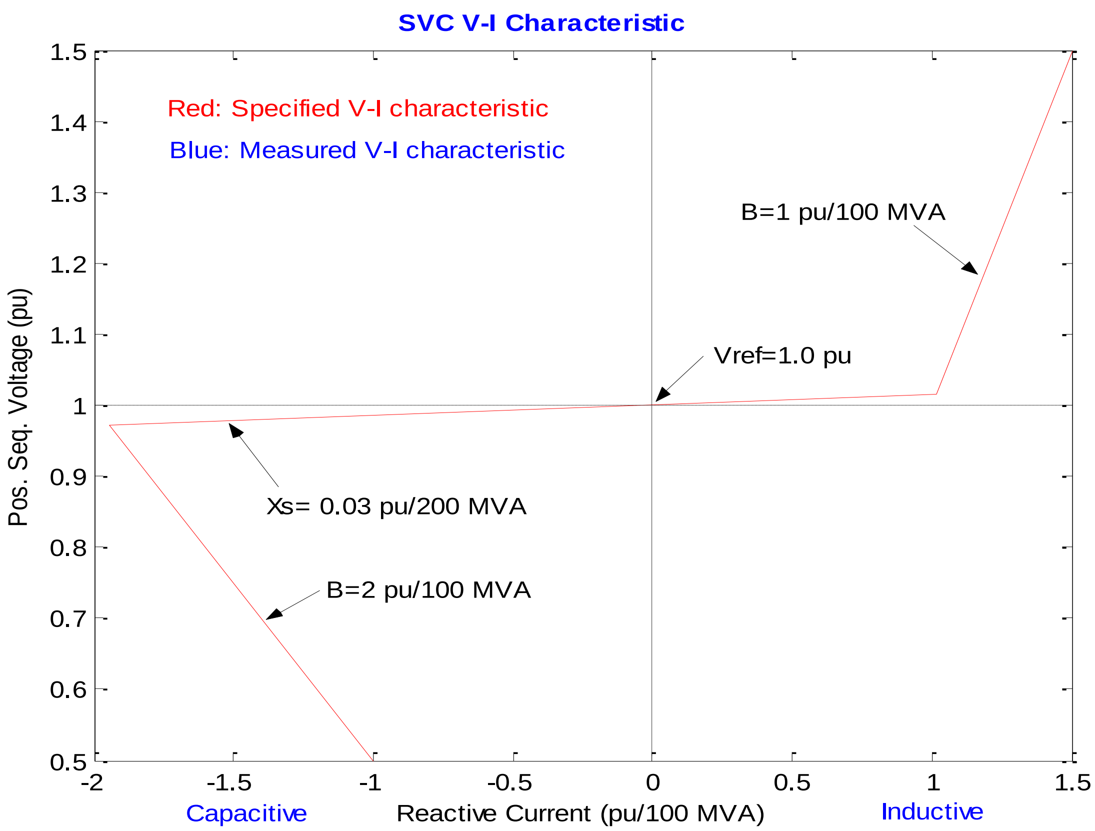

Figure 11: Voltage – Ampere Characteristics

4.0 Conclusion

In this paper, we observed that the misfiring pulse was sent when the valve voltage was maximum positive immediately after the TSC has blocked. This thyristor misfiring produces a large thyristor over-current (18 kA or 6.5 times the nominal peak current). Also, immediately after the thyristor has blocked, the thyristor voltage reaches 85 KV (3.8 times the nominal peak voltage). To prevent such over-currents and over-voltages, thyristor valves are normally protected by metal oxide arresters.

To improve the performance of the AC-DC solid state converter a good power factor correction technique is necessary, then there should be a low total harmonic distortion (THD) and low DC bus voltage. At the power factor correction stage two bulk storage capacitors are adopted. Its excellent line regulation capability makes the converter suitable for universal input application.

References

Alexander, C. and Sadiku, M. 2013. Fundamentals of electric circuits. New York, NY: McGraw-Hill. 067: 115-122

Azazi, HZ., EL-Kholy, EE., Mahmoud, SA. and Shokralla, SS. 2010. Review of Passive and Active Circuits for Power Factor Correction in Single Phase, Low Power AC-DC Converters. Proceedings of the 14th International Middle East Power Systems Conference MEPCON'10), 19-21 December, 2010. Cairo University, Egypt, paper ID 154: 217-224.

Das, M., Capell, C., Grider, D., Raju, R., Schutten, M., Nasadoski, J., Leslie, S. Ostop, J. and Hefner, A. 2011. 10kv,120 a sic half h- bridge power MOSFET modules suitable for high frequency, medium voltage applications. Energy Conversion Congress and Exposition (ECCE), IEEE, pp. 2689 -2692.

Glinka, M. and Marquardt, R. 2005. A new ac/ac multilevel converter family. Industrial Electronics, IEEE Transactions 52(3): 662 – 669.

Ioffe, A. and Regel, AR. 2017. Non crystalline, amorphous and liquid electronic semiconductors. Progress in Semiconductors, Heywood and Co Ltd, London, 321-328.

Jeong, Y. 2014. Novel methodology of ac-dc valley fill with power factor correction. http://nssemicon.com/pdf/ac_dc.pdf.

Kittel, C. 2016. Quantum Theory of Solids, Wiley, New York.

Levy, F., 2016. Physique et technologies des semi-conductors, Presses Polytechniques et Universitaires Romandes, Lausanne.

Miller, U. and Abrahams, E. 2018. Impurity Conduction at Low Concentrations. Physics Reviews, 120(3): 754–755.

Molinas, M. and Garces, A. 2012. A study of efficiency in a reduced matrix converter for offshore wind farms. Industrial Electronics, IEEE Transactions, 59 (1): 184 – 193.

Moliton, A. 2017. Basic Electromagnetism and Materials, Springer, New York.

Sedra, A. and Smith, K. 2004 Microelectronic circuits 5th Edition, Oxford University press New York