A Small Scale Static VAR Compensator for Laboratory Experiment

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Abstract— **This paper presents a small scale Static VAR Compensator (SVC) circuit that could be used as either a laboratory demonstration or a laboratory experiment. The small scale SVC lab experiment effectively demonstrates SVC's function in correcting power factor through the use of power thyristors in a phase-controlled circuit. The laboratory setup of the SVC circuit using a thyristor controlled reactor in parallel with a capacitor will discussed in this paper. Results from the lab setup to exhibit firing angle adjustment to inject or absorb VARs into the system will also be described.**

Keywords— **Static VAR Compensator, SVC, Phase-Controlled Circuit.**

I. INTRODUCTION

Energy efficiency is a topic that has become more and more prominent as demand for electrical power grows. When inductive loads are introduced to the power system by customers, the voltage at customer's point reduces. This is due to the increased load current caused by an increase in the amount of reactive power the utility has to supply to the inductive load. This further increases the systems loss and reduces the efficiency of the power system [1]. To the customer, this will cause them to pay more for the electricity bill and they may receive penalties by the utility company if the required reactive power is significant. This type of problem is typically indicated by the low power factor at the load. A widely used approach to mitigate this problem is through the use of corrective capacitors. Capacitor is an electrical component that can supply reactive power, and hence fits well for the reactive power thirst inductive load.

While using a set of capacitance (a fixed reactive power source) may be sufficient to correct power factor in predominantly inductively load; however, real world loads vary with time and hence a fixed set of capacitance can potentially lead to overcompensation. This in turn will produce an unnecessary boost in voltage which could further damage the loads. Hence, a better method to improve power factor is needed. In particular, an approach that would match the reactive power requirement of the load as it changes will be desirable.

One known technique to improve power factor or to compensate for reactive power uses power electronics. Power electronics deals with the flow control of electricity through switching or power semiconductors. Through the use solid-state switches in power electronics, continuous adjustment of reactive power may be achieved.

There are several ways to compensate for reactive power using power electronics, but one that will be the focus of this paper is the one that is called the Static VAR Compensator or SVC for short. SVC has been used by many utilities in the world, and its use will continue to grow [2].

Because of the important role SVC plays in future power systems, it is therefore crucial for future power engineers to gain full understanding of how SVC operates. While covering the topic of SVC may seem ample for students to learn the basic theory of SVC, a lab experiment will be more beneficial for the students to grasp the practical issues associated with SVC. Unfortunately, besides safety issues, the scale of a typical SVC circuit makes it impractical to have an SVC lab experiment in a school environment.

This paper describes a project that deals with the development of a small-scale SVC lab experiment suitable for university environment. The SVC experiment utilizes thyristors and makes use of commercially available thyristor firing boards from Enerpro, Inc.

II. STATIC VAR COMPENSATOR

A Static VAR Compensator consists of a Thyristor-controlled Reactor (TCR) which is an inductance in series with a bidirectional thyristor switch as shown in Figure 1. The reactor is in parallel with a corrective capacitor to adjust for a leading or lagging power factor. The main function of a SVC is to absorb or supply reactive power based on the changing VAR requirement of the load. Hence, the use of an SVC allows for the application of power factor correction to maintain the unity power factor for a variable load.
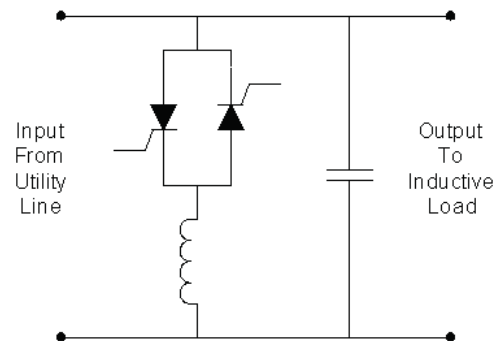

Figure 1. SVC circuit

The ability of the Thyristor-controlled Reactor (TCR) to limit current is a vital part of controlling power flow. The current is controlled by the firing angle (α), which at 0º the switch is permanently closed, then slowly limits current as α increases to 180° where current is then zero. Limiting the current ultimately limits the reactive current which results in how much reactive power can be added to or subtracted from the system. With the SVC, when α = 0 the current passes fully through the inductor bypassing the capacitor. Yet as α increase to 180°, current will be forced to slowly pass through the capacitor, and thus raise the lagging power factor of the system. Therefore the firing angle α may be directly related to how much power factor correction we need for the system. Figures 2 and 3 show the Thyristor module and the Enerpro's firing board [3] used for the SVC lab setup consecutively.
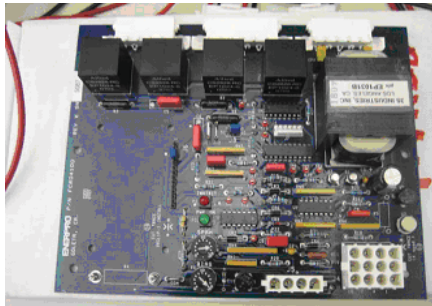

Figure 2. Power thyristor module

Figure 3. Enerpro's firing board

III. DESIGN REQUIREMENTS

To demonstrate how thyristors work, we first modelled our inductive load to consist of a 0.5 H inductor and a 150 Ω resistor readily available in each lab bench at the Power Electronics lab at Cal Poly State University. Because each 150 Ω resistor has a 0.82 A rating, the SVC circuit must be adjusted to stay within the current limit of the resistor. For the ac source we used 120Vrms ac input accessible from each lab bench for both the firing board as well as the SVC circuit. Using power meter, we measured the voltage, current, power, and power factor of inductive load to give us the required maximum capacitance of the SVC. Table 1 lists results of these measurements followed by the calculations to derive the value of maximum capacitance required for the SVC circuit. The initial power factor is quite low and hence provides a good starting value for the SVC experiment.

TABLE I
INDUCTIVE LOAD MEASUREMENTS

Voltage [V$_{rms}$]	Current [mA$_{rms}$]	Average Power [W]	Power Factor [-]
119.1	204.8	8.72	0.357

Calculation of maximum capacitance for SVC:

$$\text{Power Factor Angle} = \cos^{-1} 0.357 = 69.08^o \text{ lagging}$$

$$S = VI^* = (119.1)(204\angle 69.08^o) = 24.37\angle 69.08^o VA$$

$$Z_L = \frac{V^2}{S} = \frac{(119.1)^2}{24.37\angle 69.08^o} = 581\angle -69.08^o = 207.47 - j542.75\Omega$$

$$C = \frac{1}{(2\pi f X_L)} = \frac{1}{(377)(542.72)} = 4.887\mu F$$

While an ideal firing angle α ranges from 0-180°, the board limits the range to 5-162°. The firing board has a 1 kΩ potentiometer connected which was used to vary the firing angle α. In order to verify that the thyristors and firing board work correctly, an AC controller circuit with a resistive load was used as shown in Figure 4. The resulting relationship between the control voltage from the potentiometer to the firing angle is shown in Figure 5.
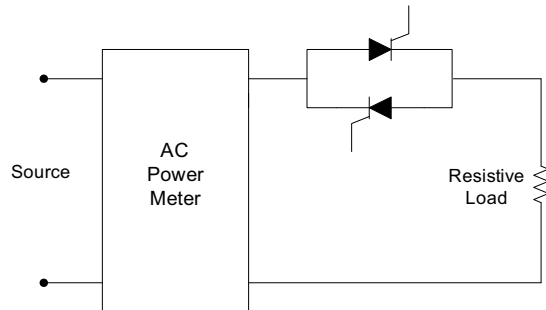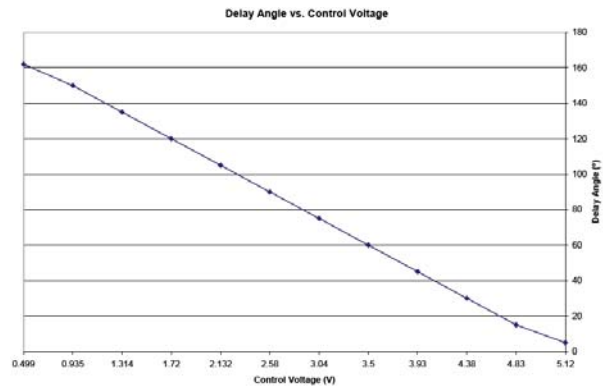

Figure 4. AC Controller Test Circuit

Figure 5. Firing angle as a function of control voltage

IV. LABORATORY SETUP AND RESULTS

Figure 6 depicts the circuit diagram for the SVC circuit. An AC power meter will be connected to the source and

the SVC circuit to monitor the change in voltage, current, power, and power factor. A multimeter was connected across the terminals of the potentiometer to measure the control voltage for changing the firing angle. The actual laboratory setup of the entire SVC circuit is shown in Figure 7.
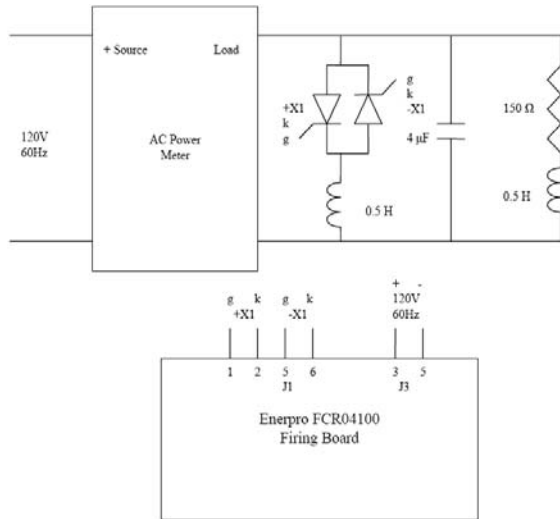

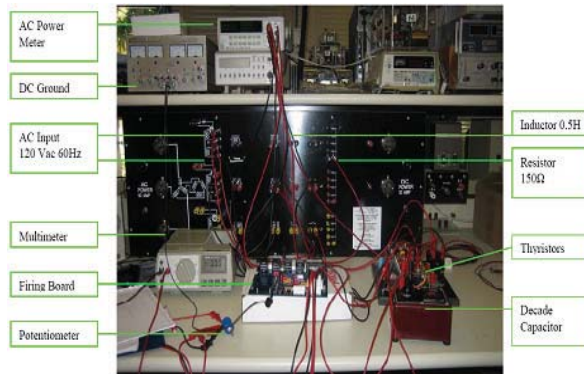Figure 6. Circuit diagram of the SVC circuit with its firing board

Figure 7. Laboratory setup for the SVC circuit

The SVC circuit should show that power factor increases as the firing angle is increased using the calculated capacitance. It is therefore best to record the power factor values according to the firing angle. Because the capacitance value came out to be 4.887μF, the 4μF and 5μF capacitor values yielded the highest power factor with maximum α angle. Also, as the capacitance increases over the calculated value, the power factor should begin to decrease due to overcompensation. While adding capacitance to a lagging system will benefit the system, too much capacitance will overcompensate and eventually lead the system which in effect decreases the power factor. When the system is leading, then more inductance is required to absorb VARs and push the power factor closer to unity again. Figure 8 is a graph of the data taken from actual measurements of the load power factor as a function of firing angle. The graph shows that the increase in power factor as firing angle increases especially when 4μF or 5μF capacitor was used. With a 3μF capacitor, the power factor is relatively lower due to lack of compensation or under-compensation. Yet, when the 6μF capacitor and above were used, the load becomes over-compensated and the power factor decreases again. Overall the graph shows that power factor increases as firing angle is increased, yet due to the overcompensation of larger capacitors, it will begin to decrease because of over-compensation.
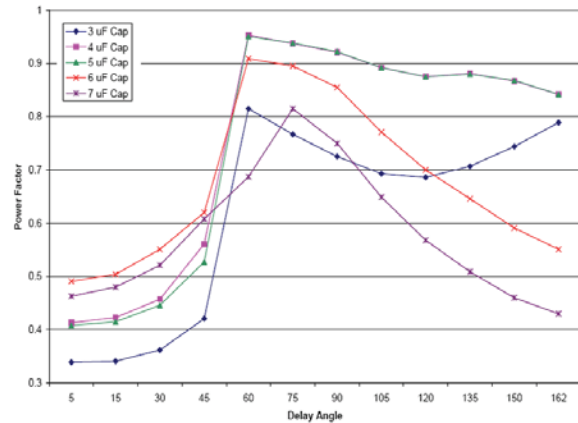

Figure 8. Power Factor measurements as a function of firing angle

V. CONCLUSIONS

In this paper, a small scale SVC circuit that could be used for laboratory experiment in university environment has been presented. The procedure started with the use of AC controller circuit which effectively showed the phase control of the thyristors. By seeing the result of the phase control on the oscilloscope, it is easier to understand exactly how the bidirectional thyristor configuration limits the voltage and current. When this controller was then connected in series with an inductor, and in parallel with a capacitor, we were able to vary the amount of capacitance or inductance added to the system in order to achieve a unity power factor. This configuration is in fact the basis for the SVC circuit.

The Static VAR Compensator showed that it is capable of improving the power factor of an inductive load. As only a non-varying inductive load was tested, the SVC is still able to accommodate for a varying load with the phase control in the thyristors. Being able to vary the capacitance or inductance of a circuit is very beneficial because it makes the correction more flexible and cost efficient. Yet, adding an overly large capacitor could result in an over-compensation which would require less delay angle for the system to be close to unity power factor.

In closing, the SVC circuit described in this paper is a lab-scale version for what utilities companies used as a way to compensate for a lagging power factor. While more efficient methods are used today, the SVC is still a great cost effective way for power factor correction. For students, the small-scale SVC circuit serves as an effective way to see how power electronics helps utilities deliver efficient power by flexible and fast adjustment of the normally lagging power systems.

REFERENCES

[1]. J. Glover, M. Sarma, and T. Overbye, *Power System Analysis and Design*, 4th ed., Toronto: Thomson 2008.
[2]. M. Rashid, *Power Electronics: Circuits, Devices, and Applications*, 3rd Edition, New Jersey: Prentice Hall 2004.
[3]. *Operating Manual for a Model FCRO4100 Single Phase Firing Circuit Board*, Enerpro Inc. Ri87A, 1997.