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Enhancement in Voltage Stability using Switched Capacitor Compensation

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Abstract — *This paper presents a novel hybrid series-parallel switched/modulated FACTS-based filter/compensation scheme (SCC) developed by the First Author for voltage stability enhancement. The proposed FACTS filter/compensation device comprises a hybrid series and shunt switched capacitor-banks controlled by a dynamic time decoupled multi-regulator multi*--loop dynamic error driven *controller. The effectiveness of the proposed low cost Pulse Width Modulated (PWM) scheme is validated using MATLAB-Simulink digital simulation results. The coordinated dynamic controller ensures FACTS device effectiveness in limiting inrush current conditions, enhancing bus voltage stabilization, improving feeder voltage regulation, reducing total harmonic distortion, and enhancing power factor at both source and load buses. For it's optimal location L-index is calculated. And it was proved by the IEEE14 Bus test system using Matlab Simulink. The voltage stability is enhance at last was proven by using the test model.*

Keywords*-SCC; Dynamic error driven loop; Line Stability Index; IEEE14 Bus*

I. INTRODUCTION

As a result of ever-increasing demand of electric power, the electricity supply industry is undergoing profound transformation worldwide. This makes the existing power transmission system highly complex. To meet the increasing demand of electricity in a power system it is essential to increase the transmitted power either by installing new transmission lines or by improving the existing transmission lines by adding new devices. Installation of new transmission lines in a power system leads to the complexities such as economic and environmental considerations that includes cost, delay in constructions so on. Flexible Alternating Current Transmission System (FACTS) technology gave up new ways for controlling power flows and enhancing the usable capacity of transmission lines. FACTS are system comprised of static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increasing the power transfer capability of the power system network. The concept of FACTS was first defined by Hingorani [1]. It usually refers to the application of High power semi conductor devices to control different parameters and electrical variables such as voltage, impedance, and phase angle, current, active and reactive power. This paper addresses the static modeling of Switched Capacitor Compensator/filter (SCC) and IEEE 14 bus system is used as the test system and their capabilities to improve the voltage profile by using MATLAB Simulink.

Advent of switched/modulated filter compensation schemes simplifies the concept of flexible FACTS-devices by combining low cost power filters with capacitor banks for power quality enhancement, flicker control, power factor correction, and electric energy loss reduction. These can be widely used in smart grid networks supplied by renewable wind and small hydro renewable energy sources [9-14].Moreover, different new/customized topologies/configurations of the modulated filter compensators are easy to design and customize with effective dynamic flexible control strategies. Active power filters can be used to fulfill power quality requirements but they are expensive and consume large current rating Other option is using the switched/modulated family of passive filters and capacitive compensators developed. Advent of Flexible A. C. Transmission System (FACTS) based Switched Capacitor Compensation (SCC) utilized with dynamic control systems for compensation of reactive power and harmonics to system In this paper a novel low-cost switched capacitor compensator (SCC) developed by the First Author is validated for power quality and power factor enhancement with effective voltage stabilization for use in smart grid-fed industrial, commercial, and residential loads, particularly for short duration short circuit and load excursions. To switch the dual IGBT/GTO switches, a multi-loop dynamic error driven coordinated dual regulation dynamic control scheme and a weighted–modified PID controller with additional error squared and rate adjusting supplementary loops for fast action are also developed.

II. SWITCHED CAPACITOR COMPENSATION[2]

The proposed FACTS SCC filter/compensation device is a low cost switched/modulated filter which comprises a series switched capacitor bank and two shunt fixed capacitor banks connected to the AC side of a three-arm uncontrolled rectifier. Two mode operations are defined for the proposed FACTS device by two controlled switches, S1 and S2, installed on the DC and AC sides of the rectifier, respectively. These two switches follow NOT LOGIC command, that is, while S1 is on,S2 is off and vice versa. Switch S1 operation dictates on-off state of the series capacitor bank. On the other hand while S2 is on, SCC compensates reactive power like a shunt capacitor bank. Configuration of the proposed SCC is shown in Fig.1.

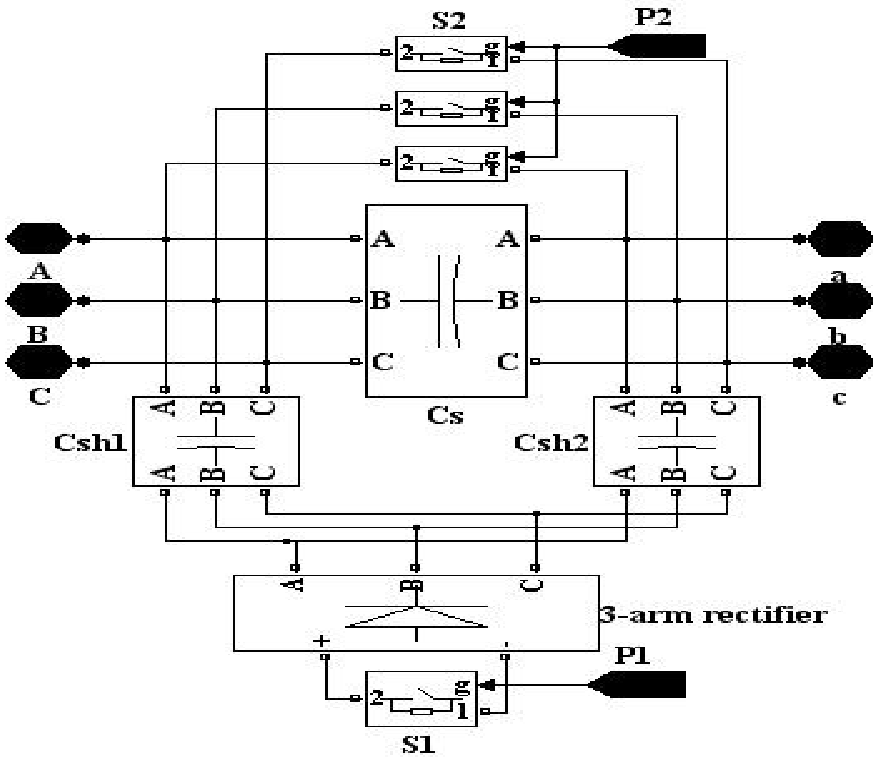


Fig 1 SCC Configuration [2]

II DYNAMIC ERROR DRIVEN CONTROLLER [3]

Block diagram of the control scheme designed for the Switched capacitor compensation is shown in Figure 2. It is based on measurement of the current Irms at the source point. The current error signal is obtained by comparing the measured Irms current against a reference current, Irms_Ref. The difference between these two signals is processed by a PI controller in order to obtain the phase angle delta required to drive the error to zero. The angle delta is used in the PWM generator as the phase angle of the sinusoidal control signal. The switching frequency used in the sinusoidal PWM generator is fs/w - 900 Hz. The control Mechanism for Switched Capacitor Compensation is described here. The major parts of controlling mechanism are PI Controller, PWM, IGBT, Low Pass Filter as Transfer function and the other controlling parameters like ABS, RMS, Weighting Factor, and Limiter are described. The whole control mechanism is based on feedback control mechanism. Source Current and Source Voltage are given to controlling mechanism. After collecting source current in feedback Harmonic error are generated, overall Total error are generated on the basis of this PI Controller are operated and compensation are provided to system.

Figure 2. Block diagram of control scheme in MATLAB Software a variable capacitor can be brought about by switch controlled capacitance which can control the fundamental component of current from zero to maximum amount. Therefore the injected reactive power to the AC bus can be controlled continuously by Switched Capacitor Compensation (SCC). Electrical loads have a combination of both active and reactive power. Active power is supplied by the generating stations while reactive power can either be supplied from the generating stations or by making use of shunt capacitor banks strategically located on the power system (or other, generally more expensive, reactive power compensation schemes).Reactive power compensation with capacitors is by far the most cost effective way to meet reactive power requirements of consumer loads. The addition of shunt capacitors releases thermal capacity in the distribution networks

by reducing current flowing through the networks, which is required to supply the loads. By Doing this we can maintain the voltage constant at each bus in IEEE14 Bus system.

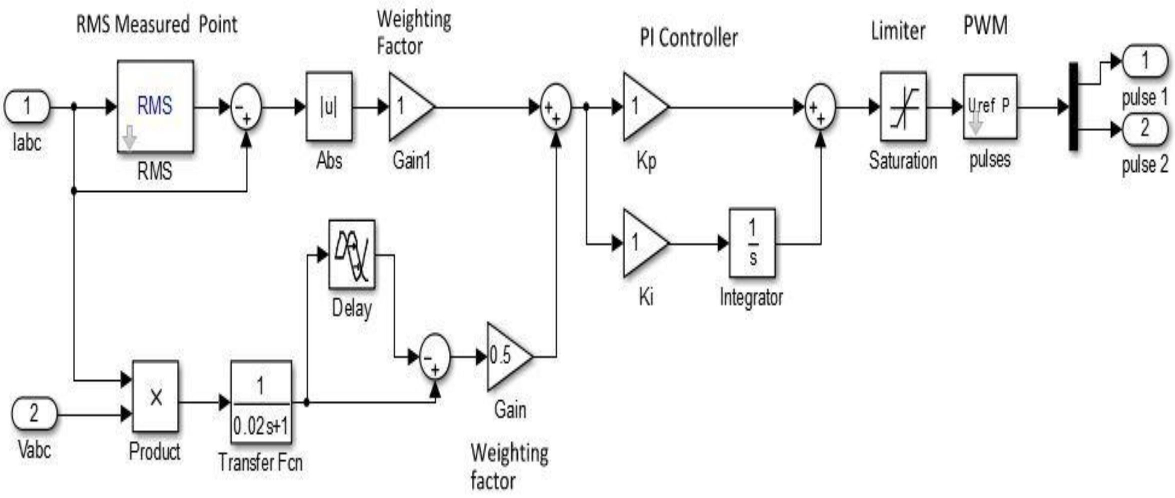


Figure 2. Block diagram of control scheme of SCC

III. STABILITY INDICES[6]

In power system, the stability level of all buses and the weakest bus among them are identified with the help of the stability indices. Lee's stability margin, Schlueter"s stability indicator, and Kassel's bus stability index, Voltage Stability Index (VSI) and Line Stability Index (LSI)[6] are the various types of stability indices used in power system to monitor the system stability. In this paper VSI and LSI are proposed to find the stability levels of all bus and lines simultaneously.

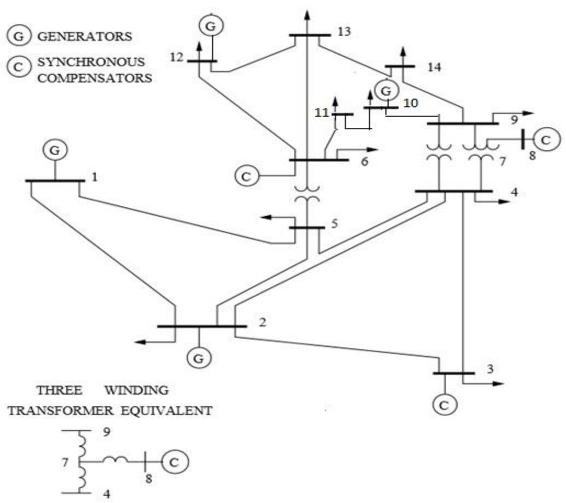
3.1 Line Stability Index (LSI) [6]: A.Y. Goharriz, R. Asghari [6] formulated a line stability index based on the power transmission concept in a single line. The line stability index, for this model, can be defined as,

$$Lmn = \frac{4XQ}{\text{Vs}\left(Sin(\theta - \delta)\right)^2}$$

Where, V_s is the sending end voltage
Q is the reactive power at receiving end
X is the reactance at receiving end
θ is the impedance angle
δ is the angle difference between the supply voltage and the receiving end voltage.[6]

Lmn calls the stability index of that line. It is used to find the stability index for each line connected between two bus bars in an interconnected network. Based on the stability indices of lines, voltage collapse can be predicted. When the stability index Lmn less than 1, the system is stable and when this index exceeds the value 1, the whole system loses its stability and voltage collapse occurs[6].

IV. IMPLEMENTATION IN MATLAB SIMULINK



The diagram shown beside is the single line diagram of IEEE14 Bus standard Test System[7] having 20 transmission lines, 4 generators, 4 synchronous compensator and voltage independent loads are used, This IEEE14 bus test system is implemented using MATLAB/SIMULINK.

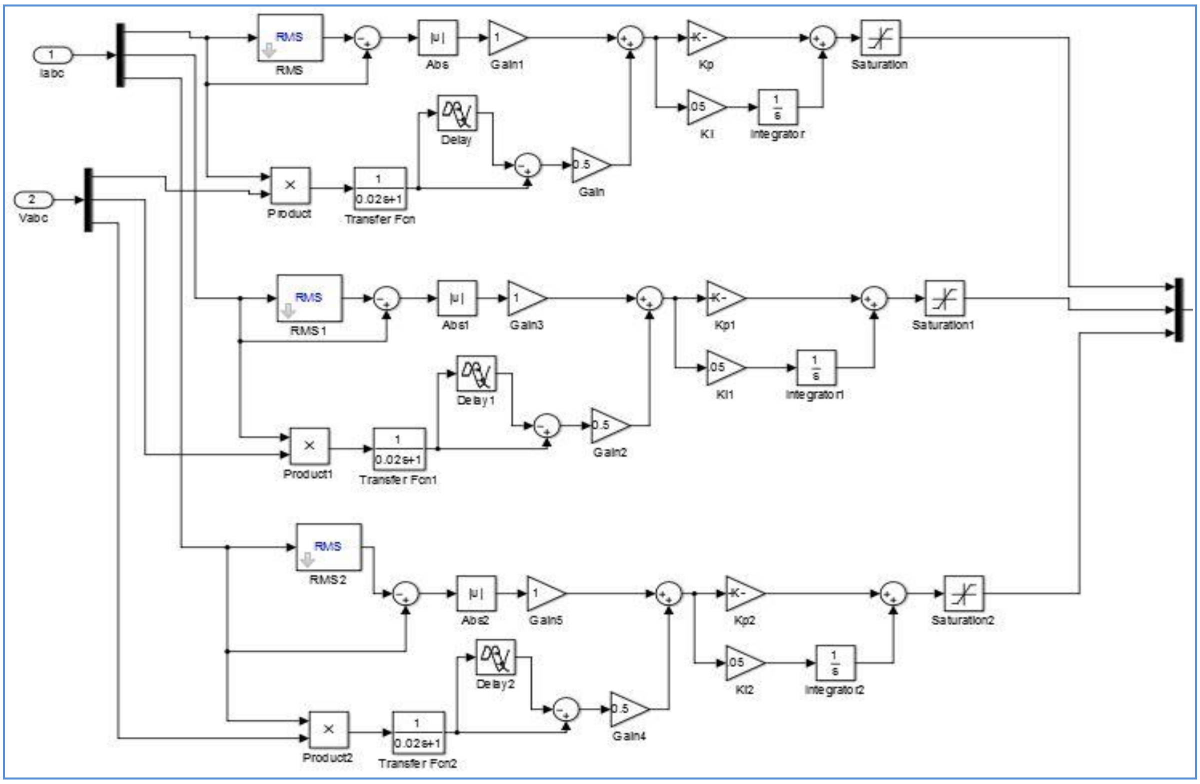


Figure 3.Simulation diagram of SCC Subsystem

The block which is shown above is the block used for the modeling of Switched Capacitor compensation and it is developed using Matlab Simulink which is connected at the 9th no of bus as we have find the LSI of line no 9 is more when compared to others which is connected between line no 9 and line no 4 so we have connected SCC at bus no 9. The figure shown above is for three different phases voltages and at the signal goes to the pulse generation block which is shown below PWM is use to generate for different 6 IGBT used for the switching purpose, at a time one from the upper half and one from the lower half is triggered.

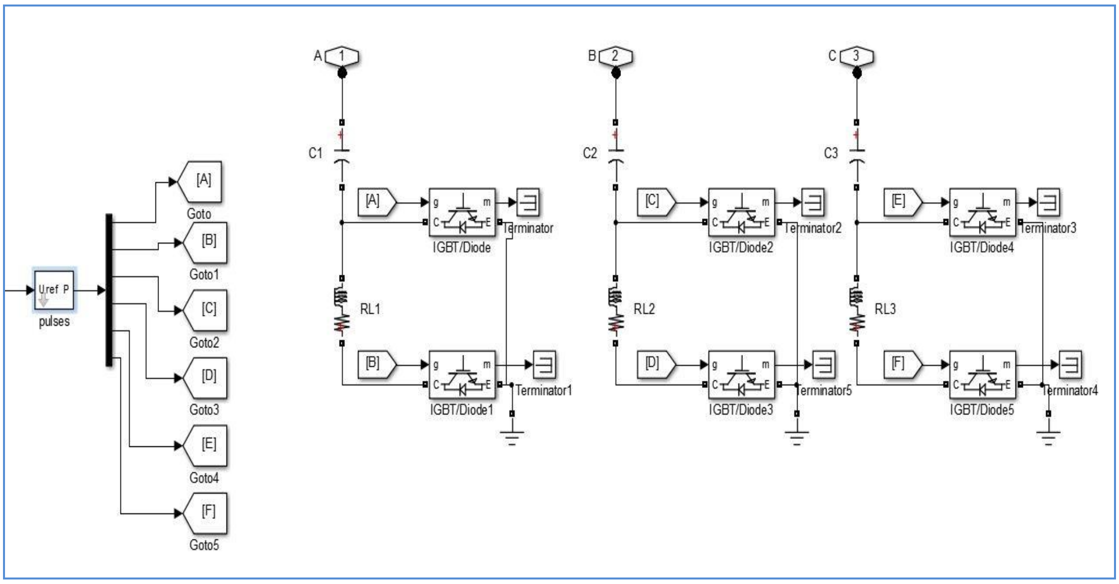


Figure 4.Simulation diagram of SCC Subsystem

The LSI values which has been calculated using the load flow of the IEEE14 Bus system using Formula of LSI shown in previous Section. From the table shown below 9th of line has the maximum value of LSI which shows that the 9th no line is the most vulnerable which is connected between bus no 4-9 so we have Placed SCC at bus no 9. MATLAB coding is used to find the value of LSI.

Table 1: LSI Results

Line no	LSI	Line no	LSI
1	0.0190	11	0.0097
2	0.0021	12	0.0185
3	0.0795	13	0.0090
4	0.0030	14	0.0670
5	0.0041	15	0.0124
6	0.0160	16	0.0022
7	0.0209	17	0.0676
8	0.0093	18	0.0084
9	0.7786	19	0.0576
10	0.0174	20	0.1465

Table 2: Voltage Profile

Bus No	Before Placing SCC	After Placing SCC	Bus No	Before Placing SCC	After Placing SCC
1	0.988	0.963	8	0.963	1.015
2	0.9805	0.978	9	0.978	1.089
3	0.944	0.992	10	0.992	1.02
4	0.96	0.975	11	0.975	0.99
5	0.969	1.01	12	1.01	1.022
6	0.988	0.9655	13	0.9655	0.977
7	0.976	0.94	14	0.94	0.955

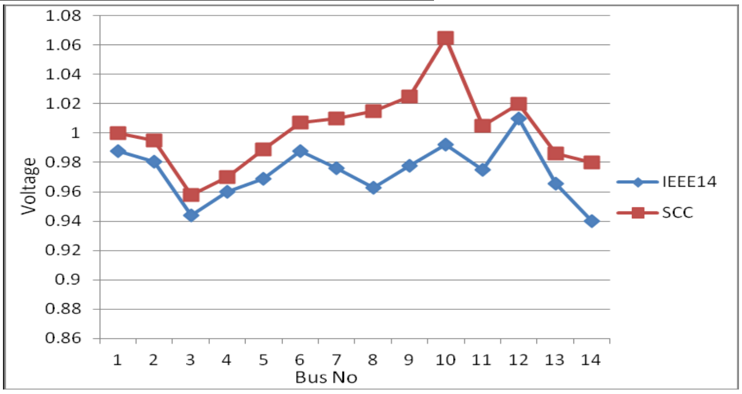


Figure 5.comparison between the voltages with and without SCC.

CONCLUSION

In this paper a novel FACTS device SCC(Switched Capacitor Compensator) is modeled and implemented on the IEEE14 Bus system and concluded that after finding the optimum location by Line Stability Index (LSI) as calculated in this paper we can get the maximum voltage stability and the stability enhancement is proved by comparing the results as shown in the figure5. beside, by placing the corresponding FACTS base device at proper location..

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