GENERATING REFERENCE CURRENT AND VOLTAGE CONTROL OF STATIC COMPENSATOR DURING VOLTAGE SAGS

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***Abstract*— Voltage sags and interruptions are generally caused by the faults such as short circuits, energization of the heavy loads , starting of the large motors ,single line to ground faults and etc. These sags produced by above causes will interrupt the system and it has to be mitigated immediately . This paper presents a complete control scheme intended for static compensators operating under these abnormal conditions .Static synchronous compensators have been broadly employed for the provision of electrical ac network services, which include voltage regulation, network balance, and stability improvement. Here the control scheme a novel reactive current reference generator loop. The reactive power support for the ac system is the main criteria for the system stabilization .This can be achieved by shunt connecting static compensator in to ac system. The current reference generator has as a main feature the capacity to supply the required reactive current even when the voltage drops in amplitude during the voltage sag. Thus, a safe system operation is easily guaranteed by fixing the limit required current to the maximum rated current..**

***Keywords*— Reactive compensation ,Static compensator, Reactive reference current generator, Voltage sag.**

I.INTRODUCTION

Modern power system comprises of complex networks, where many generating stations and load centres are interconnected through long power transmission and distribution networks [6]. Utility distribution networks, critical commercial operations and sensitive industrial loads all suffer from various types of outages and interruptions which can lead to significant financial loss, loss of production, idle work forces etc. Today due to the changing trends and restructuring of power systems, the consumers are looking forward to the quality and reliability of power supply at the load centres. A power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end use equipments. The main causes of a poor power quality are harmonic currents, poor power factor, supply-voltage variations, etc. Rapid growth of nonlinear loads leads to lots of power quality problems such as harmonics, unbalance operation and excessive source-end neutral current in three-phase supplying networks. Power flow is a function of transmission line impedance, the magnitude of the sending and receiving end voltages, and the phase angle between the voltages. By controlling one or a combination of the power flow arguments, it is possible to control the active, as well as the reactive power flow in the transmission line. In the past, power systems were simple and designed to be self-sufficient. Active power exchange of nearby power systems was rare as ac transmission systems cannot be controlled fast enough to handle dynamic changes in the system and, therefore, dynamic problems were usually solved by having generous stability margins so that the system could recover from anticipated operating contingencies .

The STATCOM has the ability to increase/decrease the terminal voltage magnitude and, consequently, to increase/decrease power flows in the transmission line. The renewable energy is the new energy growing sources which is located near the load centres .For the generation of the power with the renewable energy the ancillary services have to be provided. The main services are the reactive power requirement, voltage stability. To improve the voltage stability reactive power support is needed. For all renewable energy the reactive power control is low. As the installation of the distributed energy sources ,there is a need of control the reactive power.

A STATCOM is a shunt-connected reactive power compensation device that is capable of generating and/or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. A STATCOM can supply the required reactive power under various operating conditions, to control the network voltage actively and thus, improve the steady state stability of the network. It can be operated over its full output current range even at very low voltage levels and the maximum var generation or absorption changes linearly with the utility or ac system voltage. The abnormal operating condition of the STATCOM was studied in [2]–[5].The operation and integration of the STATCOM in a weak ac network was analyzed in [1].The voltage fluctuation will lead to the system interruption also the deviation in the voltage will reduce performance of the power electronic devices connected to the network. The objective of the paper is to mitigate the occurring of the voltage sag by giving the reactive power support to the system with the help of STATCOM. The reactive current reference generator can generate the reactive current when the system voltage reduced. .

II. STATIC COMPENSATOR

This paper focuses the reactive power support under the voltage sags. The Static compensator has to fulfil reactive power control ,reactive reference current requirement during voltage sags. When there is a fault , it has to mitigate the fault by generating the reactive current.

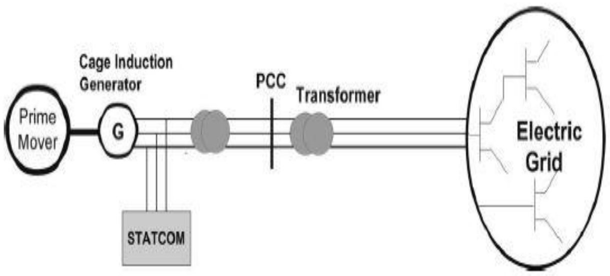


Fig. 1. STATCOM connected to the induction machine and the grid through a transformer .

The system under consideration is sketched in Fig. 1 and consists of an Induction generator directly connected to the grid through a transformer, and a STATCOM connected at the terminals of the induction machine.

A.Grid Code Requirements

The generation of power should remain connected even in faulty grid conditions and also to support the grid voltage. It should be connected even in the short duration when the voltage sag are deep. It has to supply the reactive power during voltage sag. Figure 2 shows the behavior of the Static compensator .When there is a voltage dip at the grid the reactive power injection will increase the root mean square value of the system voltage during the voltage sag. The inputs for the controller are the measured phase voltages *v* at the PCC, the currents *i* flowing and the dc-link voltage v_{dc}. Voltage *v* and current *i* are transformed into SRF values. a Sequence extractor extracts the Voltages into the symmetric components v_α and v_β . The symmetric sequence extractor is a key aspect to characterize the grid voltage. Many sequence extractors can be found in the literature to extract voltage sag information..The DC link voltage is giving the active power support . The voltage sag was detected by the voltage support block. This can be done by computing the voltage rms in each phase. When rms values drop below a predefined threshold, the voltage support control is activated. The voltage support block decides which strategy should be implemented according to grid codes and system limitations. Then the above information are given to the reference current generator. This reference current generator generates the reference current i_α^*, i_β^*. Finally the reference currents are compared with the currents in the current loop and then the duty cycle are generated by the pulse width modulator to trigger the Static compensator.

The main objective of this work is to present a method to ride through voltage sags and support the grid voltage. In three phase balanced voltage sags. the control strategy should be to raise the voltage in all phases

B. Characteristics of Voltage sag

A voltage sag is an abnormal condition in the grid voltages ,characterized by a short-time reduction in one or various phases[8]. The causes of voltage sags are

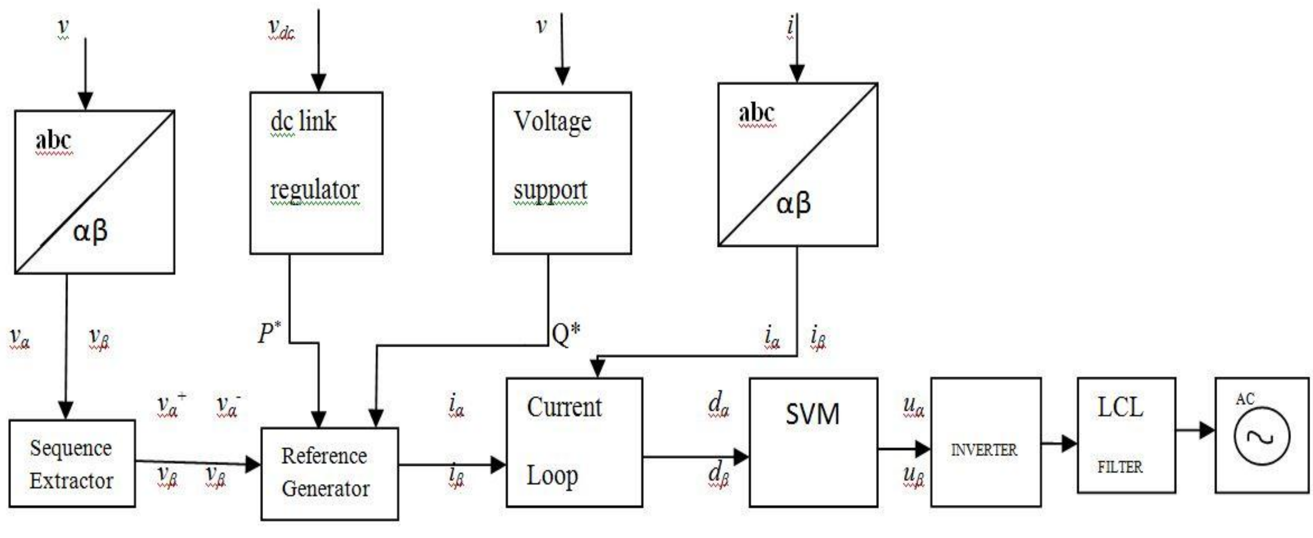


Fig.2.Control diagram of Static Compensator under fault condition

mainly phase-to-ground short circuit, phase-to-phase (to ground) short circuit, and the start-up of large motor .The most widely accepted classification of voltage sags is presented in [9].Positive sequence ,negative sequence and zero sequence voltages are three sequences .Of those zero sequences are not considered

$$v_a = v_a^+ + v_a^- + v_a^0 \tag{1}$$

$$v_b = v_b^+ + v_b^- + v_b^0 \tag{2}$$

$$v_c = v_c^+ + v_c^- + v_c^0 \tag{3}$$

Using the clarkes transformation the sequences components are extracted .The equation are follows

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{4}$$

The above phase voltages are transferred to positive and negative sequences of v_β and v_α.

$$v_\alpha = v_\alpha^+ + v_\alpha^- \tag{5}$$

$$v_\beta = v_\beta^+ + v_\beta^- \tag{6}$$

The reference current loop is responsible for generating reference current, expressed in (7) and (8), according to the set points V^*_{dc} and I^* as follows

$$i_\alpha^* = i_{\alpha p}^* + i_{\alpha q}^* \tag{7}$$

$$i_\beta^* = i_{\beta p}^* + i_{\beta q}^* \tag{8}$$

where $i_{\alpha p}^*$, $i_{\beta p}^*$, $i_{\alpha q}^*$, $i_{\beta q}^*$ are the active and reactive current references, respectively.

C. Voltage unbalance factor

The ratio of the positive sequence voltage to the negative sequence voltage at the point of coupling is known as the unbalanced factor.

$$n = \frac{v^-}{v^+} \tag{9}$$

When the n value is zero then the system voltage is balanced otherwise the system is unbalanced .According to the value of the Static compensator control circuit are depended.

D. Active and Reactive reference current generators

The current supplied to the ac network during unbalanced voltage sags can be highly distorted by harmonics. Sequence detector, together with the following active current references [7], the harmonics of the current are strongly reduced:

$$i_{\alpha p}^* = \frac{2}{3}\frac{v_\alpha^+}{\left(v^+\right)^2} p^* \tag{10}$$

$$i_{\beta p}^* = \frac{2}{3}\frac{v_\beta^+}{\left(v^+\right)^2} p^* \tag{11}$$

Also the Reactive reference current are

$$i_{\alpha q}^* = \frac{k_q v_\beta^+ + (1-k_q) v_\beta^-}{k_q\left(v^+\right)^2 + \left(1-k_q\right)\left(v^-\right)^2} Q^* \tag{12}$$

$$i_{\beta q}^* = \frac{k_q v_\alpha^+ + (1-k_q) v_\alpha^-}{k_q\left(v^+\right)^2 + \left(1-k_q\right)\left(v^-\right)^2} Q^* \tag{13}$$

Where q is the reactive element. k_q are the constants for that element

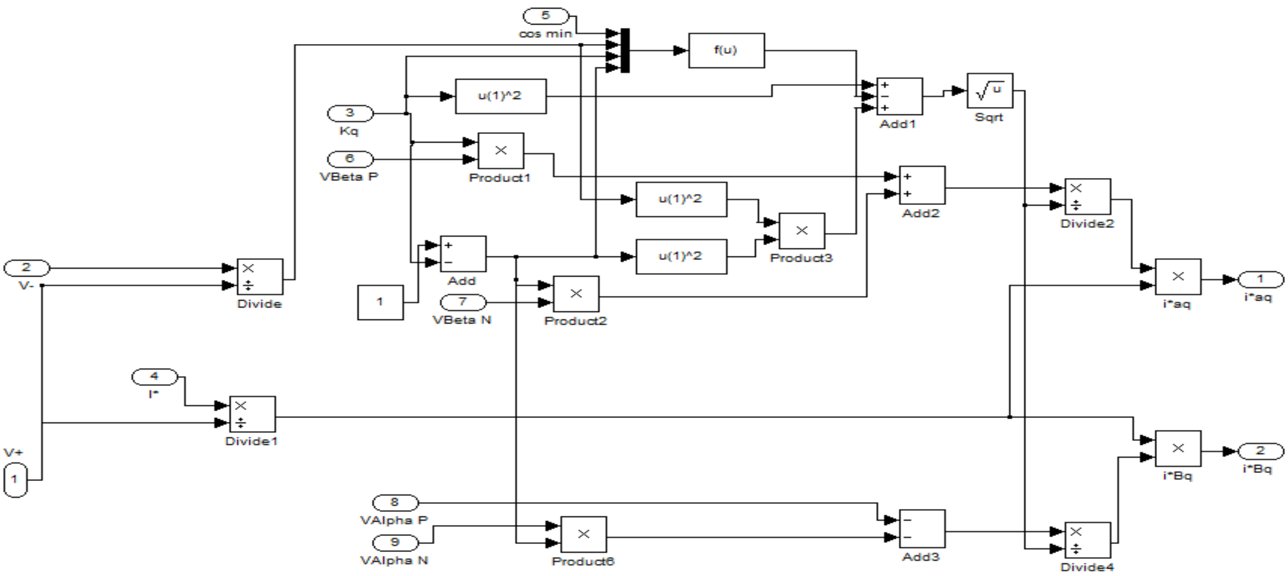


Fig3.Simulink of Reactive reference current generator using MATLAB

III.GENERATING REACTIVE REFERENCE CURRENT

From the clarkes transformation the reference current is obtained which can be written as

$$I^* = \frac{2}{3}\frac{\sqrt{k_q^2 - 2nk_q(1-k_q)\cos_{\min} + n^2(1-k_q)^2}}{k_q + n^2(1-k_q)}\frac{Q^*}{V^+} \quad (14)$$

When the value of k_q are either zero or 1.The above equation (14) will reduced to

$$I^* = \frac{2}{3}\frac{Q^*}{V^+} \quad (15)$$

Q is reactive power, injection of the reactive current in either positive or negative sequences. When the value of k_q is 1,it can be injected through positive sequence and when k_q is 0 it can be delivered through negative sequence. Clearly the value of k_q should regulated between 0 and 1 By inserting the equation (12) and (13) in above equation number (14) .The reactive reference current equation is obtained as

$$i^*_{\alpha q} = \frac{k_q v^+_\beta + (1-k_q)v^-_\beta}{\sqrt{k_q^2 - 2nk_q(1-k_q)\cos_{\min} + n^2(1-k_q)^2}}\frac{I^*}{V^+} \quad (16)$$

$$i^*_{\beta q} = \frac{-k_q v^+_\alpha - (1-k_q)v^-_\alpha}{\sqrt{k_q^2 - 2nk_q(1-k_q)\cos_{\min} + n^2(1-k_q)^2}}\frac{I^*}{V^+} \quad (17)$$

Positive- and negative sequence components of the PCC voltage are directly obtained at the output of the voltage sequence detector, as shown in Fig. 2.The two set point I^* and the control gain *kq* should be chosen in order to fulfill a specific control objective. The current set point control the reactive power delivered to the system ,so the reference of the current set point is to regulate the positive sequence voltage. When the voltage level at the point of common coupling decreases ,k_q will inject the desired voltage to the system. The negative sequence value decreases by decreasing the k_q value. Therefore the coordinated control of positive and negative sequence is employed.

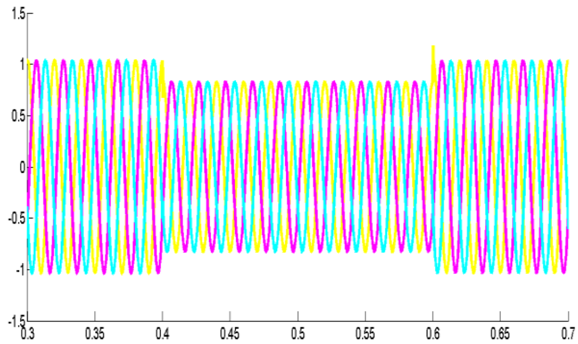
IV. EXPERIMENTAL RESULTS

The experimental validation which shows the theoretical explanation of this paper. The simulation of control circuit of the reactive reference frame is shown in Fig 3. Table I lists the control parameters of the system and the Static compensator that fulfill this requirement. The frequency of the system is assumed to be 50Hz .The voltage at the PCC has a fast enough transient response and a error in steady state is reduced since the voltage sequence detector has enough time to be updated.

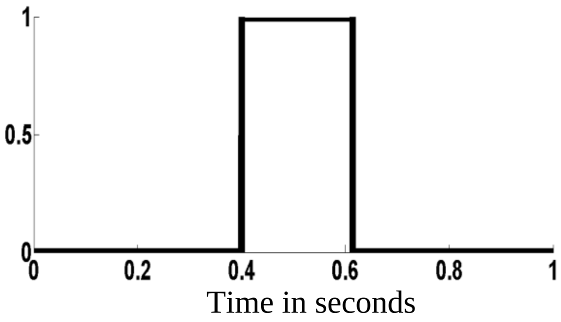
TABLE I
PARAMETERS OF THE SYSTEM AND STATIC COMPENSATOR

	Symbol	**Values**
V_g	Grid voltage	110 Kv
f_g	Frequency	50 Hz
R_s	Line resistance	$2 \times 10^2\ \Omega$
L_s	Inductance	8×10^2 H
$V_{p,v_{dc}}$	Proportional Controller Of V_{dc}	0.3V
$V_{i,v_{dc}}$	Integral controller Of V_{dc}	15Vs
V_{p,v^+}	Proportional gain Of V^+ loop	0.1V
V_{i,v^+}	Integral gain Of V^+ loop	15A/Vs
V_{p,v^-}	Proportional gain Of V^- loop	0.1V
V_{i,v^-}	Integral gain Of V^- loop	0.2A/Vs

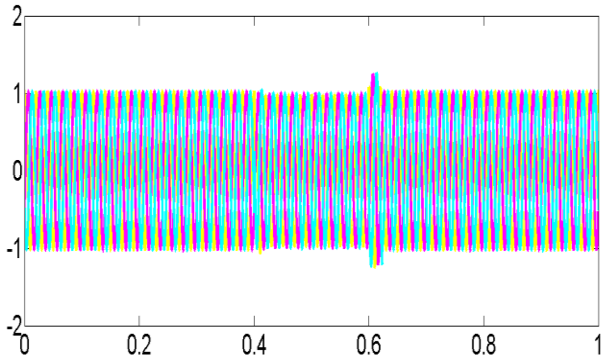
Phase voltages at the PCC for the selected voltage sags are shown in Figs. 4 and 5. Before the fault, the voltage in each phase is around 415 V. The voltage level is then converted into the per unit value. At time *t* = 0.4 s, the voltage sag occurs in the Fig 4. Instantly, the voltage support strategy is activated. Then it changes from 0.4- 0.6. For this time period the parameter is set in order to mitigate the voltage sag.The flexible properties of the proposed voltage support control scheme. The proposed STATCOM was tested with a voltage sag presented in [10].Also the voltage sag for the different time duration was simulated Fig. 5 has a large steady-state imbalance (see the time interval from 0.3 to 0.6 s) and a variable voltage profile during the transient state. For this reason, the chosen voltage sag is a good candidate to evaluate the performance of the proposed control solution in adverse stringent network conditions.



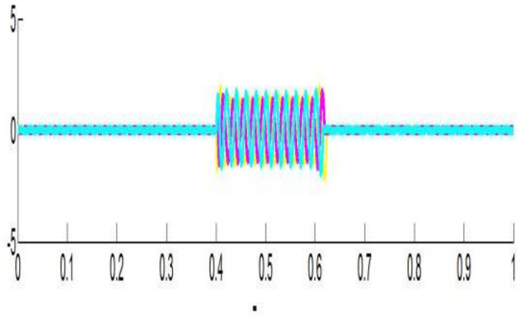
Time(sec)
(a)



(b)

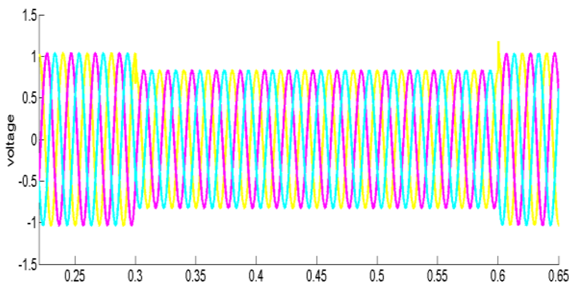


(c)

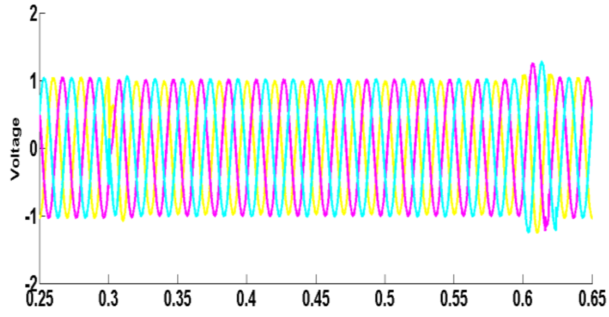


(d)

Fig.4. Voltage at the grid when the sag occurs during time period (0.4-0.6)seconds. (a) Grid voltage when Statcom was inactive (b) Switching period of control circuits (c)Compensated Grid voltage (d) Injection of reactive current.



(a)



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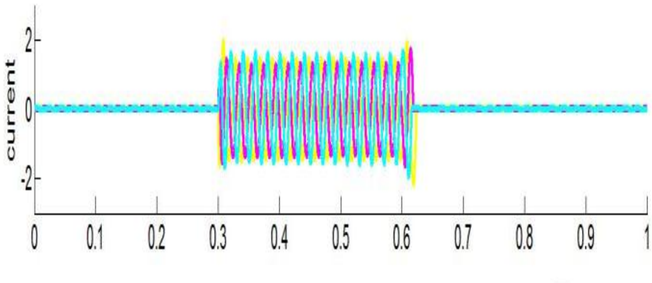

(c)

Fig.5. Voltage at the grid when the sag occurs during time period (0.3-0.6)seconds. (a) Grid voltage when Statcom was inactive (b)Compensated Grid voltage (c) Injection of reactive current.

The switching time of the Static compensator was shown in fig 4(b) .When the voltage sag occurs at any time ,voltage support detector in Fig2 deduces the sag level and also the duration of the sag. During that time interval the injection of the reactive reference was shown in Figs 4(d) and 5(c). The sag occur in the system is 20% (the voltage level reduces to 0.8pu) was shown in Fig 4(a) and Fig 5(a) shows that the 30% of the system voltage dip also compensation of the above mentioned voltage sag duration was shown in Fig 4(c) and Fig 5(b).The different type of voltage sag with the various time duration of the sag was simulated in the MATLAB. This specification defines the conventional scheme of reactive power injection by providing the minimum reactive current that must be injected during a voltage sag as a function of the voltage at the PCC. The results shows that mitigation of voltage sag by the injection of the current through the Static compensator was effective.

V. CONCLUSION

Results from a critical Sag and a generic shorter fault indicate the general applicability of the technique to adapt the STATCOM control to the needs of the system during recovery after any kind of contingencies. This voltage control scheme which has the has the advantages of 1) voltage support during sags 2) voltage regulation. Two different scenarios have been experimentally tested to illustrate the results of the proposed voltage support control with a different sag level in the various time duration. Selected experimental tests confirm the theoretical features of this control algorithm.

To verify and prove the viability and effectiveness of the proposed voltage control loop in steady-state and dynamic operation modes, a simulation model was created.. The reactive power support with the help of the STATCOM was simulated under different voltage and time duration. Simulation results show the effectiveness of STATCOM in active filtering and fluctuations of a voltage under randomly varying sag can be effectively reduced .Thus the sag occurred in the system was mitigated also AC voltage regulation and power factor of the transmission line also improved.

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