Cascaded Two Level Inverter Based Multilevel Statcom for High Power Applications

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Abstract—A simple static var compensating scheme using a cascaded two-level inverter-based multilevel inverter is proposed. It consists of two-level inverters and connected through the cascaded open-end windings of a three-phase transformer. The dc-link voltages of the inverters are regulated at two levels to obtain five-level operation. To verify the efficiency of the proposed control strategy, the MATLAB simulation results are verified at balanced and unbalanced conditions. A laboratory prototype is also developed to validate the simulation results. To investigate the behavior of the converter, the complete dynamic model of the system is developed from the equivalent circuit. The model is linearized and transfer functions are derived and system behavior is analyzed for different operating conditions.

Key Words: DC link voltage, cascaded multilevel inverter, static compensator, PI controller

I.INTRODUCTION

The application of flexible ac transmission systems (FACTS) controllers, such as static compensator (STATCOM) and static synchronous series compensator (SSSC), is increasing in power systems. This is due to their ability to stabilize the transmission systems and to improve power quality (PQ) in distribution systems. This STATCOM is accepted as a reactive power controller and replacing conventional reactive power compensators, such as the Thyristor-switched capacitor and Thyristor-controlled reactor. This device can be used for var compensation, voltage regulation etc. [1].

In this paper in high-power applications, reactive power compensation is achieved using cascaded multilevel inverters [2]. These inverters consist of a high number of dc voltage sources which are usually realized by capacitors. Hence, the converters draw a small amount of active power to maintain dc voltage of capacitors and to compensate the losses in the converter. However, due to mismatch in conduction and switching losses of the switching devices, the capacitors voltages are unbalanced. Balancing these voltages is a major research challenge in multilevel inverters. In different control schemes using different topologies are reported in [3]–[7]. However, the aforementioned topology requires a large number of dc capacitors. The control of static dc-link voltage of the capacitors is difficult.

Static reactive power compensation by cascading conventional multi-level inverter is an attractive solution for high-power applications. The topology consists of standard multilevel/two-level inverters connected in cascade through open-end windings of a three-phase transformer. Such topologies are popular in high-power drives [8]. One of the advantages of this topology is that by maintaining asymmetric voltages at the dc links of the inverters, the number of levels in the output voltage waveform can be increased. This improves PQ [8]. Therefore, overall control is simple compared to conventional multilevel inverters.

A three -level inverter and two-level inverter are connected on both side of the transformer low-voltage winding. The dc-link voltages are maintained by separate converters. In [11], standard two-level inverters is used to maintain the three level operation. The reactive power supplied to the grid that affects the dc-link voltage balance between the inverters.

Generally, a static var compensation scheme is explain a cascaded two-level inverter with multilevel inverter. Its uses standard two-level inverters to achieve five level operation. The dc-link voltages of the inverters are controls by asymmetrical levels to obtain five-level operation. The simulation found at balanced and unbalanced supply - voltage conditions. A laboratory prototype is also developed to validate the simulation results.

From this section of simulation and experimentation are found that the dc-link voltages of two inverters collapse for certain operating conditions when there is a sudden change in reference current. To develop the behavior of the converter, the complete dynamic model of the system from the equivalent circuit. The model is linear zed and transfer functions are derived. Using the transfer functions, system behavior is analyzed for different operating conditions.

This paper is organized as follows: The proposed control scheme is presented in Section II. Simulation result is presented in Section III respectively.

II.CASCaded TWO-LEVEL INVERTER-BASED MULTILEVEL STATCOM

The cascaded two level inverter-based multilevel STATCOM to obtained five level operation. The inverters are connected on the low-voltage (LV) side of the transformer and the grid connected to high-voltage (HV) side of the transformer. The dc-link voltages of the inverters are Maintained constant and modulation indices are controlled to achieve the required objective. The proposed
control scheme is derived from the ac side of the equivalent circuit.

\[ -v_c' + r_c i_c' + L_c \frac{di_c'}{dt} + (e_{c1} - e_{c2}) = 0 \]  \hspace{1cm} (3)

Where

\( v_a', v_b', v_c': \) Source voltage referred to LV side of transformer

\( r_a, r_b, r_c: \) Resistance which represent the losses of transformer

\( L_a, L_b, L_c: \) Leakage inductance of transformer winding

\( e_{a1}, e_{b1}, e_{c1}: \) Output voltage of inverter 1

\( e_{a2}, e_{b2}, e_{c2}: \) Output voltage of inverter 2

\( r_1, r_2: \) Leakage resistance of DC link capacitor \( C_1, C_2 \)

The above three equation written as

\[
\begin{bmatrix}
\frac{di_a'}{dt} \\
\frac{di_b'}{dt} \\
\frac{di_c'}{dt}
\end{bmatrix} =
\begin{bmatrix}
x & 0 & 0 \\
0 & x & 0 \\
0 & 0 & x
\end{bmatrix}
\begin{bmatrix}
i_a' \\
i_b' \\
i_c'
\end{bmatrix} + \begin{bmatrix}1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{bmatrix}\begin{bmatrix}v_a' - (e_{a1} - e_{a2}) \\
v_b' - (e_{b1} - e_{b2}) \\
v_c' - (e_{c1} - e_{c2})
\end{bmatrix}
\]  \hspace{1cm} (4)

The above equation represent mathematical model in stationary reference frame. The system model is transformed to synchronous rotating reference frame [14].

\[
\begin{bmatrix}
\frac{de_d^*}{dt} \\
\frac{de_q^*}{dt}
\end{bmatrix} =
\begin{bmatrix}
x & \omega \\
-\omega & x
\end{bmatrix}\begin{bmatrix}i_d^* \\
i_q^*
\end{bmatrix} + \begin{bmatrix}1 & 0 \\
0 & 1
\end{bmatrix}\begin{bmatrix}v_d^* - e_d^* \\
-v_q^*
\end{bmatrix}
\]  \hspace{1cm} (5)

Comparison speaks to the numerical model of the fell two-level inverter-based multilevel STATCOM in the stationary reference outline. This model is changed to the synchronously turning reference outline. The \( \pm \) tomatohawks reference voltage segments of the converter \( e_{d1}^* \) and \( e_{q1}^* \) are controlled as1

\[
e_d^* = -x_1 + \omega Li_d + v_d^* \]  \hspace{1cm} (6)

\[
e_q^* = -x_2 + \omega Li_q + v_q^* \]  \hspace{1cm} (7)

Where \( v_d^* \) is the \( \pm \) hub voltage segment of the air conditioner source and \( i_d^*, i_q^* \) are \( \pm\) tomatohawks current segments of the fell inverter, individually. The synchronously turning casing is adjusted to source voltage vector so that the \( \pm \) segment of the source voltage of \( v_d^* \) is made zero. The control parameters \( x_1 \) and \( x_2 \) are controlled as takes after:

\[
x_1 = \left(k_{p1} + \frac{k_{iq}}{s}\right)(i_d^* - i_d') \]  \hspace{1cm} (8)

\[
x_2 = \left(k_{p2} + \frac{k_{iq}}{s}\right)(i_q^* - i_q') \]  \hspace{1cm} (9)

The \( \beta \)-axis reference current \( i_d^* \) is achieved by

\[
i_d^* = \left(k_{p3} + \frac{k_{iq}}{s}\right)[(V_{d1c} - V_{d2c}) - (V_{dc1} + V_{dc2})] \]  \hspace{1cm} (10)
Where $V_{dc1}, V_{dc2}$ are the reference and real dc-join voltages of inverters 1 and 2, individually. The q-axis reference current $i_q^*$ is acquired either from an external voltage regulation circle when the converter is utilized as a part of transmission-line voltage bolster or from the heap if there should arise an occurrence of burden remunerate.

**A. Control Strategy**

The control unit outline is appeared in Fig.4. The square flags $\cos \omega t$ and $\sin \omega t$ are created from the stage bolted circle (PLL) by method for three-stage supply voltages $(V_a, V_b, V_c)$. The converter streams $(i_a^*, i_b^*, i_c^*)$ are changed to the synchronous turning reference casing utilizing the unit signals. The exchanging recurrence swell in the converter current segments is dispensed with utilizing a low-pass channel (LPF). From $V_{dc1}^*, V_{dc2}^*$ and $i^*$ circles, the controller creates d-q tomahawks reference voltages, $e^d$ and $e^q$ for the fellinverter. With these reference voltages, the inverter supplies the sought receptive current and draws required dynamic current to manage complete dc-join voltage $V_{dc1}^* + V_{dc2}^*$.

**B. DC-Link Balance Controller**

The dynamic force exchange between the source and inverter relies on upon $\delta$ and is generally little in the inverters supplying var to the matrix. Henceforth, canbethoughttobecorrespondingto $e^q$ Consequently, the - hub reference voltage part of inverter-2 $e_{q2}^*$ is inferred to control the dc-join voltage of inverter-2 as is derived to control the dc- link voltage of inverter-2 as

$$e_{q2}^* = (k_p s + k_i \frac{s}{s}) (V_{dc1}^* + V_{dc2}^*) \quad (11)$$

The reference voltage part of inverter-1 $e_{q1}^*$ is gotten as The dc-join voltage of inverter-2 $V_{dc2}$ is controlled at 0.366 times the dc-join voltage of inverter-1 $V_{dc1}$. It results in four-level operation in the yield voltage and enhances the consonant range. Communicating dc-join voltages of inverter-1 and inverter-2 regarding complete dc-join voltage $V_{dc}$ as

$$V_{dc1} = 0.73V_{dc} \quad (12)$$

$$V_{dc2} = 0.268V_{dc} \quad (13)$$

Since the dc-join voltages of the two inverters are directed, the reference - pivot voltage part $e_d^*$ is partitioned in the middle of the two inverters in extent to their individual dc-join voltage as

$$e_{d1}^* = 0.732e_d^* \quad (14)$$

$$e_{d2}^* = 0.268e_d^* \quad (15)$$

Diminishes. Hence, power exchange to inverter-2 increments, when it decreases for inverter-1 The force exchange to inverter-2 is straight measured, when for inverter-1, it is controlled by implication. Along these lines, through unsettling influences, the dc-join voltage of inverter-2 is restored to its reference fatly contrasted with that of inverter-1. Utilizing and, the reference voltages are created in stationary reference outline for inverter-1 and utilizing and for inverter-2. The reference voltages produced for inverter-2 are in stage restriction to that of inverter-1. From the reference voltages, door signs are produced utilizing the sinusoidal heartbeat width regulation (PWM) strategy. Since the two inverters' reference voltages are in stage resistance, the prevalent symphonies show up at twofold the exchanging recurrence.

**III SIMULATION RESULTS**

The implemented Simulink model consisted of three phase voltage source it is acts as a supply system which is distributed the power to load by utilizing the distribution transformers at normal and abnormal conditions. In any distribution mechanism the efficiency levels are reduced due to the presence of disturbances which leads to reduced power quality in thenetworks.

To improve the power quality levels in the system facts technology provided in this model. The model designed with cascaded two level STATCOM is interconnected in parallel in distribution network. The block diagram which is shown in figure 5.
The statcom consisted the two voltage source converter which is used identify the faulted conditions in the networks by the controlling strategies. Each voltage source converter having six IGBTs to detect the faults and to compensate the faults by proper firing pulses from the controller. The dc-link capacitance which is used to charge the energy at normal conditions and to release energy levels at abnormal conditions.

**IV CONCLUSION**

DC-link voltage balance is one of the main problems in cascaded inverter-based STATCOMs. In this paper, a simple var compensating scheme is proposed for a cascaded two-level inverter-based multilevel inverter. The scheme provides regulation of dc-link voltages of inverters at asymmetrical levels and reactive power compensation. The performance of the scheme is validated by simulation and experimentations under balanced and unbalanced voltage conditions. Further, the cause for instability when there is a change in reference current is investigated. The dynamic model is developed and transfer functions are derived. System behavior is analyzed for various operating conditions. From the analysis, it is inferred that the system is a nonminimum phase type, that is, poles of the transfer function always lie on the left half of the s-plane. However, zeros shift to the right half of the s-plane for certain operating conditions. For such a system, oscillatory instability for high controller gains exists.

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