Power Quality improvement by using DSTATCOM in power distribution system fed BLDC motor

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Abstract: A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a miss operation of end userequipment’s. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. With therestructuring of power systems and with shifting trend towards distributed and dispersed generation, the issue of power quality. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. Distribution static compensator (DSTATCOM) is a shunt compensation device that is generally used to solve power quality problems in distribution systems. DSTATCOM forces load to operate always at rated power. Hence, customers need to pay for constant power continuously, whereas rated heating losses will take place in the equipment for entire operation. This concept proposes a hybrid control algorithm to maximize utilization and functionality of distribution static compensator (DSTATCOM). In this paper, implementing Power quality circuit with voltage source converter in the BLDC Motor drive is developed. The control of BLDC drive used is Field Oriented Control using pulse with Modulation. The power quality circuit proposed here improves the power factor and reduces harmonic distortion. Simulation work is performed using MATLAB/SIMULINK environment.

Key Words: DSTATCOM, power Quality, BLDC motor, Distribution Generation.

I INTRODUCTION

Electric power distribution network have become more increasingly important and plays an essential role in power system planning. This type of power systems has a major function to serve distributed customer loads along a feeder line; therefore under a competitive environment of electricity market service of electric energy transfer must not be interrupted and at the same time there must provide reliable, stable and high quality of electric power [1-2]. However, one might consider an additional device to be installed somewhere in the network. Such devices are one of capacitor bank, shunt reactor, series reactors [3-4], and automatic voltage regulators and/or recently developed dynamic voltage restorers, distribution static compensator (DSTATCOM), or combination of them [5-6]. The DSTATCOM [9-10] is a voltage source converter (VSC) based custom power technology which can perform as a reactive power source in power systems. The D-STATCOM [7] can regulate magnitude of voltage at a particular AC bus, at the point where it is connected, via generating or absorbing reactive power from the system. D-STATCOM acts as a shunt compensator connected in parallel to the system so that it can inject appropriate compensation currents. The D-STATCOM has several advantages compared to a conventional static var compensator (SVC). The D-STATCOM gives faster response and can produce reactive power at low voltages [8]. Also, it doesn’t
require thyristor-controlled reactors (TCR) or thyristor-switched capacitors. In present day distribution systems (DS), major power consumption has been in reactive loads. The typical loads may be computer loads, lighting ballasts, smallrating adjustable speeds drives (ASD) in air conditioners, fans, refrigerators, pumps and other domestic and commercial appliances are generally behaved as nonlinear loads [9-10]. These loads draw lagging power-factor currents and therefore give rise to reactive power burden in the DS. Moreover, situation worsens in the presence of unbalanced and non-linear loads, affect the quality of source currents to a large extent. It affects the voltage at point of common coupling (PCC) where the facility is connected. This has adverse effects on the sensitive equipments connected to PCC and may damage the equipment appliances [11].

In this paper, a hybrid control scheme has been proposed to maximize the DSTATCOM utilization while considering the above mentioned issues. Instantaneous symmetrical component theory, with flexibility of choosing pf, is used to compute reference source currents [12]. The reference load voltages are computed such that the least allowable pf is maintained at the PCC. Consequently, load power is appropriately controlled and advantages of energy conservation are also achieved. If reference load voltage at the predefined minimum pf comes less than the lowest allowable operating voltage, then pf is improved to get new reference load voltage. Therefore, proposed scheme ensures that energy conservation is achieved while drawing allowable reactive power from the source.

The BLDC Motor used to make low power rating application devices such as Refrigerator, WashingMachine, House-hold appliances, Medical Equipment, Wide speed range of servo drives and industrial robots. BLDC drives are used for its high efficiency, fast dynamic response and small size etc. For the operation of BLDC Drive first need to convert AC supply powerto DC power using rectifier circuit and then DC powerto variable magnitude and variable frequency AC power to feed BLDC.

II SYSTEM DESCRIPTION

Circuit configuration of a DSTATCOM, as shown in Fig.1, is connected at the PCC in a three-phase four-wire distribution system. $v_{sj}$, $v_{tj}$, $i_{sj}$, and $i_{lj}$ are source voltage, load voltage, source current, and load current respectively, where j=a, b, c represent phases. Rs and Xs represent the source impedance in three phases. The load consists of a diode rectifier feeding an RL load plus an unbalanced linear load. The DSTATCOM uses two-level, neutral-point-clamped VSI topology due to its ability to control the operation of each VSI leg independently. The dc link capacitors are represented by $C_{dc1} = C_{dc2} = C_{dc}$, whereas the voltages maintained across them are $V_{dc1} = V_{dc2} = V_{dc} = V_{dcref}$. An LC filter is used at the front end of VSI to achieve an appropriate output voltage at the PCC.

III PROPOSED HYBRID CONTROL ALGORITHM

Objective of proposed hybrid control algorithm based DSTATCOM is to reduce the voltage and current harmonics, balance the source currents, improve the pf, compensate for voltage disturbances such as sag and swell, reduce the losses in VSI, reduce the rating of VSI, and control the load power for energy conservation while analyzing their effects on the consumers.

During normal operating conditions, at which system operates most of the time, it is desired that harmonic component of load current is supplied by the filter. Additionally, pf at the PCC is maintained in such a way that the penalty for reactive power drawn from the source is avoided. In literature, several reference generation schemes have been proposed. In this paper, instantaneous symmetrical component theory (ISCT) based algorithm is used for computation of reference source currents due to its flexibility in achieving desired pf [11]. Following three conditions are simultaneously satisfied while using ISCT based algorithm:

1. Source neutral current should be zero
\[ i_{sa} + i_{sb} + i_{sc} = 0 \]  

(1)  

2. A definite angle \( \phi_{vi+} \) between fundamental positive sequence load voltage and source current \( v_{ta1+} \) and \( i_{la1+} \) respectively is maintained. Considering for phase- \( a \)

\[ \angle v_{ta1+} = \angle i_{ta1+} + \phi_{vi+} \]  

(2)  

3. Source must supply average load power \( P_{lavg} \) and VSI losses \( P_{loss} \). Source power is given as

\[ P_s = \frac{1}{T} \int_{t_1}^{t_1+T} \left( v_{la} i_{la} + v_{lb} i_{lb} + v_{lc} i_{lc} \right) dt = P_{lavg} + P_{loss} \]  

(3)  

where

\[
\begin{cases}
P_{lavg} = \frac{1}{T} \int_{t_1}^{t_1+T} \left( v_{la} i_{la} + v_{lb} i_{lb} + v_{lc} i_{lc} \right) dt \\
P_{loss} = \frac{1}{T} \int_{t_1}^{t_1+T} \left( v_{la} i_{la} + v_{lb} i_{lb} + v_{lc} i_{lc} \right) dt
\end{cases}
\]  

(4)  

Solving (3.1), (3.2), and (3.3) expressions for reference source currents are given as follows:

\[
\begin{align*}
i_{sa} &= \frac{v_{ta} + \beta (v_{ta} - v_{tc})}{\sum_{j=1,b,c} v_{tj}^2} (P_{lavg} + P_{loss}) \\
i_{sb} &= \frac{v_{tb} + \beta (v_{tb} - v_{ta})}{\sum_{j=1,b,c} v_{tj}^2} (P_{lavg} + P_{loss}) \\
i_{sc} &= \frac{v_{tc} + \beta (v_{ta} - v_{tc})}{\sum_{j=1,b,c} v_{tj}^2} (P_{lavg} + P_{loss})
\end{align*}
\]  

(5)  

Where

\[ \beta = \frac{\tan \phi_{vi+}}{\sqrt{3}} \]

The phase- \( a \) load voltage and source current are given as follows:

\[
\begin{align*}
v_{sa}(t) &= \sqrt{2} V_s \sin(\omega t - \delta) \\
i_{sa}(t) &= \sqrt{2} I_s \sin(\omega t - \delta - \phi_{vi+})
\end{align*}
\]  

(6)  

Phase-a source voltage is given as

\[ v_{sa} = \sqrt{2} V_s \sin \omega t \]  

(7)  

Applying Kirchhoff’s voltage law between source and load points

\[ V_{sa} = V_{ta} + I_{sa} (R_s + j X_s) \]  

(8)  

Using (6) and (7) in (8), we have

\[ V_{sa}(0) = V_{ta}(0) - \delta + \left[ I_{sa}(0) \{ -\delta - \phi_{vi+} \} \right] Z_s \theta_{vi+} \]  

(9)  

Where

\[ Z_s = \sqrt{R_s^2 + X_s^2} \]  

and \[ \theta_z = \tan^{-1} \frac{X_s}{R_s} \]

Equating real and reactive part in both the sides of above equation

\[
\begin{align*}
V_{sa} - I_{sa} Z_s \cos(\phi_{vi+} + \delta - \theta_z) &= V_{ta} \cos \delta \\
- I_{sa} Z_s \sin(\phi_{vi+} + \delta - \theta_z) &= V_{ta} \sin \delta
\end{align*}
\]  

(10)  

Squaring and adding the above equation

\[
\frac{V_{sa}^2}{V_{ta}^2} = \frac{I_{sa}^2}{I_{ta}^2} + 2 \left[ I_{sa} Z_s \cos(\phi_{vi+} + \delta - \theta_z) \right] + 2 \left[ I_{sa} Z_s \sin(\phi_{vi+} + \delta - \theta_z) \right]
\]  

Finally, load voltage will be

\[ V_{sa} = \sqrt{\frac{V_{sa}^2}{V_{ta}^2} + I_{sa}^2 Z_s^2} \cos(\phi_{vi+} + \delta - \theta_z) \]  

(11)  

With balanced supply, computed rms load voltage will be same for all three-phases and it will be used as \( V_s \) for further explanations. Once the expression for load voltage from above equation is computed, reference load voltage magnitude for several DSTATCOM operating conditions will be developed. The flow chart of choosing the suitable reference load voltage is given in Fig.2 and explained as follows.

a) Source Voltage Is Less Than 0.9 Pu:

Voltage sag, which is most common voltage disturbance, is defined as the decrease in voltage from 0.9 pu to 0.1 pu for half cycle to one minute. Hence, if load voltage goes below 0.9 pu, then system experiences sag. During sag, primary aim of the compensator is to protect the load from this...
load voltage disturbance. In conventional VCM operation of DSTATCOM, load voltage is maintained at 1.0 pu during sag. It results in more current injection by the VSI, increased losses in VSI, and rated power drawn by the load. In this paper, the reference load voltage is set at 0.9 pu during voltage sag. At this voltage, following features are obtained

i. Load will remain operational even during voltage disturbances.
ii. Load will draw minimum power, as compared to rated power in conventional DSTATCOM operating in VCM.
iii. Filter current will less compared to conventional VCM operation. Hence, VSI losses will decrease and so, efficiency will increase. Moreover, size of VSI can be reduced due to reduced current requirement.

b) Source Voltage Is Greater Than 0.9 Pu:
When source voltage is greater than 0.9 pu, then it is necessary to find appropriate reference load voltage. Conventional CCM operation of DSTATCOM maintains UPF at the PCC. Usually, most of the utilities permit customers to draw allowable reactive power without paying for tariff (however, it may vary depending upon customers). Therefore, from customer point of view, it is not necessary to maintain UPF at PCC. In proposed scheme, we have considered that the customers are allowed to operate load up to 0.9pu without any penalty. Keeping this into account, reference source currents are calculated using instantaneous symmetrical component theory at a pf of 0.9. i.e., β= 0.28. With this source current, load voltage is calculated using (12). At this voltage, following conditions are possible:

1) Vta is Less Than 0.9 pu: This voltage is computed at the lowest permissible value of pf. But, improvement in pf will increase the load voltage. Therefore, pf is improved in a fixed step of 0.05 from previous value of 0.9 pu and modified reference source currents are again computed using (5). For this current, modified load voltage is computed. If this voltage becomes greater than 0.9 pu then same voltage is used as reference load voltage. This method gives following advantages:
   i. Source currents will be balanced and sinusoidal.
   ii. Reduced currents are supplied by the filter compared to conventional CCM operation. Therefore, VSI losses decrease and its efficiency increases.
   iii. Load voltage is lesser compared to conventional CCM operation. Hence, power drawn by the load will decrease. It will reduce the power tariff, reduce the heating loss, and increase the device life.

   However, if the load voltage is not more than 0.9 pu, then above process is repeated until the load voltage becomes more than 0.9 pu. But, there must be a limit on the value of pf that can be achieved. Our objective is to keep load operational by keeping load voltage within the permissible range, while ensuring that allowable amount of reactive current is also drawn from the source. Importantly, load voltage will be more as compared to conventional CCM operation if pf is set to leading. It will force load to draw additional real power. Therefore, maximum pf is limited to 1.0. If load voltage does not become greater than 0.9 pu with this pf, then a flat voltage of 0.9 pu is set as reference load voltage.

2) Vta is Less Than 1.0 pu: This is the normal operating conditions as load voltage lies between 0.9 pu to 1.0 pu, where system operates most of the time. The reference load voltage is set at a value obtained from (12). This voltage will indirectly control the source currents and maintains 0.9 pf at the PCC. Therefore, operation of proposed scheme in this case will be similar to conventional CCM operation of DSTATCOM. However, following additional advantages are achieved in proposed scheme:
   i. Predefined minimum pf is maintained at the PCC by the compensator. Hence, filter currents are reduced. Consequently, VSI losses decreases and its efficiency increases.
   ii. The least pf at PCC makes load voltage lesser compared to conventional DSTATCOM operating in CCM. Hence, power drawn by the source decreases. It reduces the power tariff, reduce the heating loss, and increase the device life.

3) Vta is Greater Than 1.0 pu: Maintaining load voltage at a value greater than 1.0 pu forces load to draw more power than the rated power. Further, filter will have to supply more reactive current to maintain this voltage. If load voltage comes more than 1.0 pu, then source voltage is also more than 1.0 pu. This voltage is computed at a pf of 0.9. If load voltage does not become less than 1.0 even for 0.9pf, a flat voltage of 1.0 is set as reference voltage. In this case, performance of DSTATCOM and load in proposed scheme will be same as that of conventional DSTATCOM operating in VCM.

IV BLDC MOTOR
BLDC engine comprises of the perpetual magnet rotor and an injury stator. The brushless engines are controlled utilizing a three stage inverter. The engine obliges a rotor position sensor for beginning and for giving legitimate compensation arrangement to turn on the force gadgets in the inverter extension. In light of the rotor position, the force gadgets are commutated consecutively every 60 degrees. The electronic compensation takes out the issues connected with the brush and the commutator plan, in particular starting and destroying of the commutator brush course of action, along these lines, making a BLDC engine more rough contrasted with a dc engine. Fig.4 demonstrates the stator of the BLDC engine and fig.5 shows rotor magnet plans.
The brush less dc engine comprise of four fundamental parts Power converter, changeless magnet brushless DC Motor (BLDCM), sensors and control calculation. The force converter changes power from the source to the BLDCM which thus changes over electrical vitality to mechanical vitality. One of the remarkable highlights of the brush less dc engine is the rotor position sensors, in view of the rotor position and order signals which may be a torque charge, voltage summon, rate order etc; the control calculation s focus the entryway sign to every semiconductor in the force electronic converter.

The structure of the control calculations decides the sort of the brush less dc engine of which there are two principle classes voltage source based drives and current source based drives. Both voltage source and current source based commute utilized for perpetual magnet brushless DC machine. The back emf waveform of the engine is demonstrated in the fig.5. Be that as it may, machine with a non sinusoidal back emf brings about diminishment in the inverter size and lessens misfortunes for the same influence level.
Fig 9 Matlab/simulation circuit of with DSTATCOM configuration in a distribution system.

Fig 10 simulation wave form of source voltage and current

Fig 11 simulation wave form of dc voltage.

Fig 12 simulation wave form of filtering voltage.

Fig 13 simulation wave form of load filter voltage.

Fig 14 simulation wave form of source side power factor.

Fig 15 simulation wave form of RMS voltage.

Fig 16 simulation wave form of RMS current

Fig 17 simulation wave form of reactive power
A new hybrid DSTATCOM with reduced dc-link voltage has been discussed in detail which has the ability to compensate the load improving power quality of distribution system. Design of various parameters and control theories involved in this study were explained. In this paper, a control algorithm has been proposed for the generation of reference load voltage for a voltage-controlled DSTATCOM. The performance of the proposed scheme is compared with the traditional voltage-controlled DSTATCOM. This scheme not only provides several PQ improvement features but also reduces load real and reactive power, filter current requirement to achieve desired compensation performance, and leads to reduction in the size of VSI. Extensive simulation studies validate effectiveness of the proposed BLDC drive to study the characteristics, and to achieving good performance.

**REFERENCES**


