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Deadbeat Predictive Control Algorithm for Interactive DSTATCOM

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Abstract: **To address controls of conventional current control mode (CCM) and voltage control mode (VCM) operations. An improved performance connected distribution static compensator (DSTATCOM) has been used. The proposed interactive scheme arrange smooth change of modes of operation while remaining connected in distribution system .In normal operation ,the DSTATCOM operates in CCM to make supply currents balanced ,sinusoidal, and at unity power factor. During voltage disturbances, the CCM operation cannot improve the load voltage. In that case, DSTATCOM operation is changed to VCM which maintaining a constant voltage crosswise the sensitive loads .Hence ,this interactive DSTATCOM ensure continues, flexible, and powerful operation of the load. Also, the filter current needs are reduced in proposed scheme which decreases the losses in filter and feeder, increases inverter efficiency ,and requires reduced rating inverter for sag mitigation .This operation and control for both the operating mode are analyzed. The detailed process of the flexible transfer between the two mode is derived. Deadbeat predictive control algorithms for CCM as well as VCM operation are developed for quick operation during mode transfers. The performances of proposed scheme are validated by both simulation and experimental result.**

Keywords: **Voltage control mode, Current control mode, Power factor.**

I. INTRODUCTION

Distribution Static Compensator (DSTATCOM) is a shunt compensator which can compensate for power quality problems such as current harmonics, current unbalance, and reactive current, etc. supply voltage imperfections. A distribution static compensator (DSTATCOM) is a voltage source inverter (VS1)-based power electronic device. Usually, this device is supported by short-term energy stored in a DC capacitor. When a DSTATCOM is associated with a particular load, it can inject compensating current so that the total demand meets the specifications for utility connection. Alternatively, it can also clean up the voltage of a utility bus from any unbalance and harmonic distortion. For load compensation using a DSTATCOM, one of the major considerations is the generation of the reference compensator currents. There are several methods that have been developed for the use of the compensator when it tracks these reference currents, there by injecting three-phase currents in the AC system to cancel out disturbances caused by the load. Most of these methods carry an implicit assumption that the voltage at the point of common coupling is tightly regulated and cannot be influenced by the currents injected by the shunt device.

II. DSTATCOM IN POWER DISTRIBUTION SYSTEMS

A DSTATCOM is capable of compensating either bus voltage or line current. If it operates in a voltage control mode, it can make the voltage of the bus to which it is connected a balanced sinusoid, irrespective of the unbalance and distortion in voltage in the supply side or line current. Similarly when operated in a current control mode, it can force the source side currents to become balanced sinusoids. It is assumed that consumers are supplied from these buses. A DSTATCOM can be connected in any of these buses, depending on whether it belongs to the utility or a particular customer. For example, if the voltage at bus is distorted, it affects customers both at buses 3 and 4. The utility may then install a DSTATCOM at

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this bus to clean up its voltage. On the other hand, suppose that the consumer at bus 4 has loads that draw unbalanced and distorted current from the supply. In order to avoid a penalty, one option for the consumer is to install a DSTATCOM on its premises, so that the current drawn from bus 4 is a balanced sinusoid. A DSTATCOM can be realized using a VSI and a DC storage capacitor. One of the requirements of a DSTATCOM in a three-phase four-wire distribution system is that it is capable of injecting three unbalanced and distorted currents into the AC system, to cancel voltage or current unbalance or distortions. We therefore need a DSTATCOM that is able to force three independent currents through three phases. The problem of using an ordinary three-phase bridge inverter as the power circuit of the DSTATCOM is that the sum of three currents must be equal to zero.

III. MODES OF DSTATCOM

DSTATCOM has two modes of operations;

Current Control Mode (VCM)

Voltage Control Mode (CCM)

(A)CURRENT CONTROL MODE (CCM):

In this mode, it is assumed that the installation and maintenance of the DSTATCOM is the duty of an individual customer, so that the load does not disturb other Customers, with its unbalance or harmonic distortion. This may be a very stringent condition on the customer, especially when the supply-side voltage is unbalanced or distorted. Nevertheless, we present some design approaches, based on which the customer can draw sinusoidal current from the feeder. We consider three different cases:

(i) When both source and load are unbalanced.

(ii) When both source and loads are unbalanced, and the Load is distorted.

(iii) When both source and load are unbalanced as well as distorted.

(B)VOLTAGE CONTROL MODE (VCM):

A DSTATCOM, when operated in voltage control mode (VCM), is one of the most effective device used for load voltage regulation. In VCM operation, the DSTATCOM regulates load voltage at a constant reference value by supplying appropriate fundamental reactive current into the source.

Therefore, VCM operation of DSTATCOM provides stable and continuous operation of the load. However, conventional VCM operation of DSTATCOM maintains an arbitrary chosen voltage of 1.0 p.u. at the load terminal. For this voltage at load terminal, source exchanges reactive power even at normal operating conditions. This continuous reactive power exchange results in more reactive current flow in the voltage source inverter (VSI) as well as feeder. Consequently, losses in the VSI and feeder increase. Therefore, VCM operation of DSTATCOM is not required during normal supply conditions.

IV. DSTATCOM STRUCTURE

The power circuit diagram of a DSTATCOM connected at point of common coupling (PCC). It is realized by a three-phase, four-wire VSI with two dc link capacitors. An LC filter is connected between the VSI and PCC.

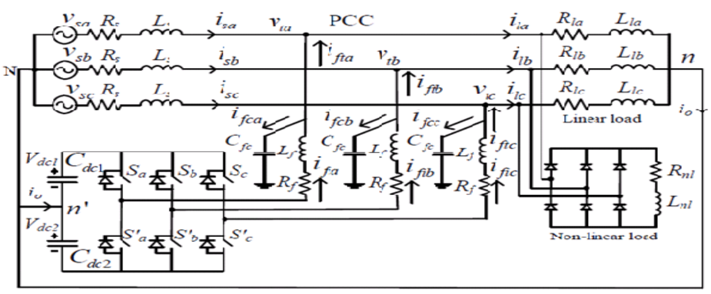

Fig:1 Power circuit diagram of DSTATCOM

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Shunt capacitor, connected across PCC helps in elimination of high-switching frequency components and prohibits them to enter into the source. Voltages across both the dc capacitors = = are maintained at a constant value = = . Source voltages, PCC voltages, load currents, source currents, and filter currents are vsj , vlj , ilj ,isj , and iftj , respectively with j = a, b, c as three phases.

V. CONTROLLER DESIGN

These include the control of DC link voltage in both CCM and VCM. In VCM it need to control of DC link voltage it result to but in CCM it result to

(A)CONTROL OF DC LINK VOLTAGE:

(a) Control of dc Link Voltage in VCM:

Average real power at the PCC () is sum of average load power () and VSI losses () .The power,, is taken from the source depending upon the angle between source and load voltages i.e., load angle &. The VSI losses are compensated by taking small real power, from the source. If capacitor voltage is regulated to a reference value, then in steady state condition is a conconstant value and forms a fraction of. Thus, is also a constant value. Once operation mode of DSTATCOM is transferred to VCM, dc link voltage is regulated by generating a suitable value of . The total dc link voltage is compared with a reference voltage and error is passed through a PI controller. Output of the PI controller, is given as

(1)

Where and are proportional and integral gains of the PI controller, respectively. For stable operation, the value of & must lie from 0 to 90 degree. Consequently, controller gains are quite small and are chosen carefully.

TABLE 4.1 Parameters used in simulations

System quantities	Values
Source voltage	230 V rms (L-N), 50 Hz
Feeder impedance	$Z_s = 0.785 + j3.14\,\Omega$
Linear load	$Z_{la} = 60 + j62.8\,\Omega$, $Z_{lb} = 40 + j78.5\,\Omega$, $Z_{lc} = 50 + j50.24\,\Omega$
Non-linear load	$25 + j47.1\,\Omega$
VSI parameters	$V_{dc} = 600$ V, $C_{dc} = 3000\ \mu$F $C_{fc} = 10\ \mu$F $L_f = 5$ mH, $R_f = 0.01\ \Omega$
PI controller gains	Kpv = $7 * C_{fc} 10^{-6}$, Kiv = $8 * 10^{-6}$, Kpc = 20, Kic = 1

(b)Control of dc Link Voltage in CCM:

Let the total losses in the VSI be represented by These losses must be supplied by the source for keeping dc link voltage constant. These are computed using a proportional-integral (PI) controller at positive zero crossing of phase-a voltage. It

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helps in maintaining the dc link voltage at a predefined reference valueby drawing a set of balanced currents from the source and is given as

(2)

Where, and = - are proportional gain, integral gain, and voltage error of the PI controller, respectively.

VI. GENERATION OF REFERENCE QUANTITES

(A)Generation of Reference Filter Currents:

Performance of a DSTATCOM in CCM mainly depends upon generation of reference filter currents. In this work, reference filter currents (i*fta, i*ftb, and i*ftc) are generated using instantaneous symmetrical components theory as following.

i*fta=ila-i*la-vta1/d1(+) (3)

i*ftb=ilb-i*lb-vtb1/d1(+) (4)

i*ftc=ilc-i*lc-vtc1/d1(+) (5)

where

d1=Losses in the inverter, are calculated using the PI controller. Average load power,, is calculated using a moving average filter

as follows:

=(vta*ila+vtb*ilb+vtc*ilc)dt (6)

Where terms t1 and T are arbitrary time instant and time period, respectively

The voltages v+ta1, v+tb1, and v+tc1 are maintained at the PCC and hence, are reference voltages of shunt capacitors. Reference currents through these capacitors lead their respective terminal voltages by 90 degree. Therefore, reference currents through these capacitors are computed as follows:

=jwC (7)

Finally, reference currents of the VSI will be given as

= + (8)

Deadbeat current predictive control is used to realize these currents using the VSI.

(B)Generation of Reference Load Voltages:

DSTATCOM compensates voltage disturbances by injecting reactive currents. To keep filter current minimum, the load voltages are maintained at 0.9 and 1.1 p.u. during sag and swell, respectively. This improves the voltage regulation capability of DSTATCOM compared to conventional VCM where load voltage magnitude is set at 1.0 p.u. By knowing the zero crossing of phase-a source voltage, choosing suitable reference load voltage magnitude ()and computing load angle .The three-phase reference load voltages are given as follows:

=sin(wt-) (9) =sin(wt-2π/3-) (10) =sin(wt+2π/3-) (11)

Where system frequency. These voltages are realized by the VSI using deadbeat voltage predictive control law.

VII. FLEXIBLE MODE TRANSFER VOLTAGE RANGE FOR INTERACTIVE DSTATCOM

Generally, loads perform satisfactorily within the _10% range of the nominal voltage (i.e., 0.9 to 1.1 p.u.), also called normal operating conditions. In these conditions, current related PQ problems are of the main concern. Therefore, DSTATCOM is operated in CCM for load harmonic reactive current compensation. It results in balanced and sinusoidal source currents with unity power factor at the PCC. However, the load voltage can change at any time due to voltage disturbances. This will result in performance deterioration the sensitive loads making CCM operation of DSTATCOM redundant. In this case, DSTATCOM must switch to VCM from CCM to protect sensitive loads from these unwanted variations in voltage by maintaining a constant voltage at the load terminal. In this section, a control algorithm for flexible mode transfer between CCM to VCM and vice versa has been presented. At any time of DSTATCOM operation, relation between the source and load points from Fig. 2 is given as follows:

=+ (12)

The DSTATCOM operating in CCM maintains unity power factor at the PCC. Therefore, the source current and the load voltage will be in-phase with the each other. =, =0, *=0, and =+j* are replaced in the above equation. After simplification, we get

=++j (13)

Equating the magnitude of both sides of the above equation, following relation are obtained:

=(+)^2 +()^2 (14)

Rearranging the above equation, the load voltage magnitude is

=^2- (15)

()/= r; ( )/= x as p.u resistance and reactance, respectively, will result into

=[1-(/)^2-()/] (16)

It can be observed that the load voltage magnitude will reduce with the increase in load power and maximum reduction will be at the base load. Also, both the feeder resistance and inductance contribute in the load voltage drop. From above equation, it is clear that the minimum source voltage at which the load voltage does not become less than 0.9 p.u. must be computed at the base value of the feeder impedance. If load voltage is more than 0.9 p.u. for maximum load then it will certainly be more than 0.9 p.u. for other loads. Also, it is required to find out minimum operating source voltage at which the load voltage will be more than 1.1 p.u. of the nominal voltage, i.e., the load experiences voltage swell. If load voltage is less than 1.1 p.u. for the lowest possible value of the load power, then it is valid for all other loads. Even though this scheme does not require knowledge of source impedance throughout the DSTATCOM operation, several schemes for online grid impedance measurement have been available.

Let us consider that subscripts '1' and '2' represent voltage sag and swell, respectively. Therefore, above equation leads into two different equations.

(17) (18)

The base value of the source resistance and reactance are 0.05 and 0.2 p.u. respectively. Also, minimum value of source impedance can be zero. After substituting these values in the above equation, following two relations are obtained:

(19) (20)

Several schemes have been presented to estimate source voltage for different applications like grid connected inverters, rectifier operation, motor drive application, renewable energy applications, power quality control, etc. The source voltage measurement schemes used in above applications are equally applicable for DSTATCOM application as well. Therefore, it is assumed that the measurement of source voltage is available.

Based on above equation, a source voltage range is derived for CCM operation of the DSTATCOM. Any voltage deviation from this range is an indication of the voltage disturbance and the DSTATCOM mode will be transferred to VCM. From load voltage is 0.9748 p.u. for a source voltage of 1.0 p.u. under the worst normal operating conditions. The voltage sag refers to reduction in load voltage from 0.9 to 0.1 p.u. of nominal value for half cycle to one minute . It means that if Vs. is 0.9232 p.u. then PCC will experience sag. Thus, it is possible to set limit for sag occurrence as Vs = 0.9232 p.u. and is denoted as lower limit. A swell is defined as increase in terminal voltage from 1.1 to 1.8 p.u. from nominal

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voltage for half cycle to one minute. From, Vs = 1.1 p.u. will produce a swell at PCC at worst normal operating condition and is denoted by upper limit. Thus, it can be concluded that:

(1) If Vs is less than 0.9232 p.u. and greater than 1.1 p.u then the DSTATCOM can operate in VCM to regulate load voltage.

(2) If source voltage lies between 0.9232 to 1.1 p.u. then the DSTATCOM can operate in CCM.

VIII. CONTROL STRATEGY FOR DSTATCOM

Control strategy for the DSTATCOM based on Artificial Immune System (AIS). The control strategy contains a GTO based square wave voltage source converter (VSC) is used to generate the alternating voltage from the DC bus. In this type of inverters, the fundamental component of the inverter output voltage is proportional to the DC bus voltage. So, the control objective is to regulate VDC as per requirement. Also, the phase angle should be maintained so that the AC generated voltage is in phase with the bus voltage. The schematic diagram of the control circuit is shown in Fig. 2

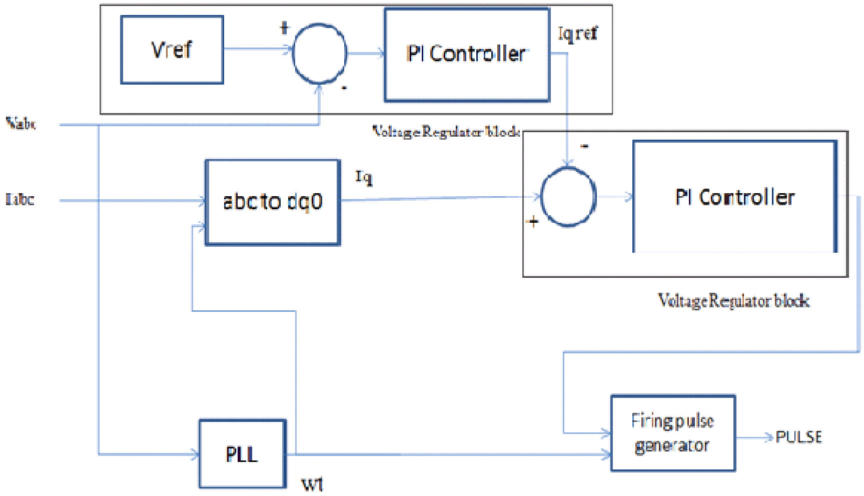

Fig : 2 Control structure for the DSTATCOM

Reduction in Power Rating:

Since the conventional CCM operation of DSTATCOM is not useful during voltage disturbances, it is not considered here. However, the ratio of reactive power requirement in proposed scheme (Spro) and conventional VCM (Scon) during sag is computed as follows:

Spro/ Scon=18/27=0.67 (21)

Reduction in Losses:

Losses in the feeder and interfacing filter are given as follows:

= (22) = (23)

Losses in the feeder as well as interfacing filter are also decreased. The losses can be computed using above equation. Further, reduction in VSI current decreases the power losses in the IGBT switches of the inverter, improves the efficiency, and reduces the electromagnetic interference.

IX. CONCLUSION

Operation and control of an improved performance interactive DSTATCOM has been proposed in this paper. The simple control algorithm proposed here, defines a range of supply voltage for which DSTATCOM operates in CCM to mitigate current related PQ problems. During voltage disturbances, operational mode of the DSTATCOM is transferred into VCM from CCM to protect the sensitive loads. The scheme ensures continuous operation of the load. Moreover, losses in feeder

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and VSI are reduced which improves efficiency of the system. Additionally, these advantages are achieved using a reduced power rating VSI.DSTATCOM that can be operated in either the voltage or current control mode. In the voltage control mode, it can make a utility bus voltage sinusoidal against any unbalance, harmonic or flicker in the source voltage, or unbalance or harmonic in the load current within the bandwidth. Proper care has been taken in designing feedback control in this mode, such that the DSTATCOM need not inject real power in the steady state. A utility may operate a DSTATCOM in this mode for a particularly problematic bus from the point of view of voltage distortion. In the current control mode, a consumer can employ the DSTATCOM such that it can inject a balanced sinusoidal current in the AC system, irrespective of unbalance and distortion in its load.

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