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INSTANTANEOUS POWER CONTROL AND POWER FACTOR IMPROVEMENT USING D-STATCOM DEVICE-REVIEW

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Abstract: The main aim of this paper is to represents a modified instantaneous power control scheme of D-STATCOM for power factor and harmonic compensation. The proposed control strategy has been introduced in order to enhance some steady state performances besides its functional elimination of power quality disturbances. Power factor and harmonic current of a controlled feeder section are two vital roles in steady-state power distribution system operation. Utilizing an already install D-STATCOM to achieve these additional control objectives can help system operators to maximize overall system performances. Otherwise D-STATCOM FACTS device are used for power quality enhancement and harmonic reduction in the power system but the proposed control strategy provides additional objectives for system performance improvement.

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 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. To complete this challenge, it requires careful design for power network planning. Nowadays the most used charging devices for EV/HEV are unidirectional, that means they allow having power flow from grid to the vehicle battery, but many research institutions are trying to apply bidirectional charging devices, with battery to grid power flow. Some solutions have the battery, or some other energy source, like super capacitors or flywheels, included directly in the charging stations or UPS systems. Usually super capacitors in EV/HEV applications are used as hybrid energy sources together with other energy storage devices. In comparison with batteries the charging/discharging times of super capacitors are significantly shorter, which makes them an ideal solution for the devices that use electric motors to smooth the start-up current and voltage peaks. Battery energy storage system (BES) has the following features: modularity, environmentally benign, high efficiency, quick response. In that case using EV/HEV batteries could be reasonable. The ratio of the real power flowing to the apparent power in the circuit called power factor shows the amount of useful power transferred in an electric power system. With a power factor close to 1 the real power flow is highest and the grid does not contain reactive currents. The higher reactive currents increase the energy lost in the power system, and require larger wire cross section and other equipment, what increase the cost of full system. Different devices are used for power factor correction. The main principle of compensating device to produce the reactive current, that is opposite to reactive current source. Power factor compensating device needed to be putted as close as possible to the reactive power source to absorb reactive power near the load. There exist many different ways to do so. 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, and automatic voltage regulators and/or recently developed dynamic voltage restorers, distribution static compensator (DSTATCOM), or combination of them. The DSTATCOM is a voltage source converter (VSC) based custom power technology which can perform as a reactive power source in power systems. The D-STATCOM 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. From D-STATCOM literature, a majority of research works have been conducted in order to enhance electric power quality due to distribution voltage variations, e.g. voltage sags or swells. Apart from these voltage variations, the D-STATCOM is capable to enhance steady-state performances such as power factor and harmonic of a particular feeder portion. In this paper, a control scheme with constant power and sinusoidal current compensation is exploited. In order to correct the power factor additionally, a power factor control loop is required and therefore included in the control block.

II. D-STATCOM WORKING

A. Description of D-STATCOM Operation

A D-STATCOM consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Figure-1 shows the schematic diagram of D-STATCOM.

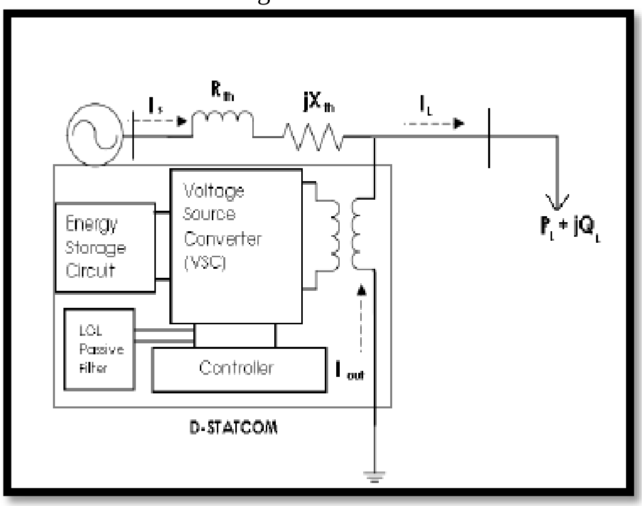

Figure: 1 Schematic diagram of a DSTATCOM

III. OVERVIEW OF D-STATCOM

The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator that is used for the correction of line currents. Connection (shunt) to the distribution network is via a standard power distribution transformer. The DSTATCOM is capable of generating continuously variable inductive or capacitive shunt compensation at a level up its maximum MVA rating. The DSTATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations. The major components of a DSTATCOM are shown in Fig.1. It consists of a dc capacitor, one or more inverter modules, an ac filter, a transformer to match the inverter output to the line voltage, and a PWM control strategy. In this DSTATCOM implementation, a voltage-source inverter converts a dc voltage into a three-phase ac current that is synchronized with, and connected to, the ac line through a small tie reactor and capacitor (ac filter).

Iout = IL – IS =IL – ((Vth - VL)/Zth) …….(1)

Iout < γ = IL < (-θ) – (Vth/Zth) < (δ-β) + VL/Zth < (-β) ...(2)

Iout =Output current
IS = Source current
IL = Load current
Vth = Thevenin voltage
VL = Load voltage
Zth = Impedance

Referring to the equation (1), output current, Iout will correct the voltage sags by adjusting the voltage drop across the system impedance, (Zth ***=R+jX***). It may be mentioning that the effectiveness of D-STATCOM in correcting voltage sags depends on:

a) The value of Impedance, Zth ***= R+jX***
b) The fault level of the load

IV. VOLTAGE SOURCE CONVERTER

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the „missing voltage". The „missing voltage" is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics. A special gate unit and voltage divider across each IGBT maintain an even voltage distribution across the series connected IGBTs. The gate unit not only maintains proper voltage sharing within the valve during normal switching conditions but also during system disturbances and fault conditions. A reliable short circuit failure mode exists for individual IGBTs within each valve position. Depending on the converter rating, series-connected IGBT valves are arranged in either a three-phase two-level or three level bridges. In three-level converters, IGBT valves may also be used in place of diodes for neutral point clamping. Each IGBT position is individually controlled and monitored via fiber optics and equipped with integrated anti parallel, free-wheeling diodes. Each IGBT has a rated voltage of 2.5 kV with rated currents up to 1500 A. Each VSC station is built up with modular valve housings which are constructed to shield electromagnetic interference (EMI). The valves are cooled with circulating water and water to air heat exchangers. PWM switching frequencies for the VSC typically range between 1-2 kHz depending on the converter topology, system frequency and specific application.

Energy Storage Circuit

Energy storage circuit is connected in parallel with the DC capacitor. The circuit carries the input ripple current of the converter and it is the main reactive energy storage element. The DC capacitor could be the charged by the battery source or could be recharged by the converter itself.

Controller

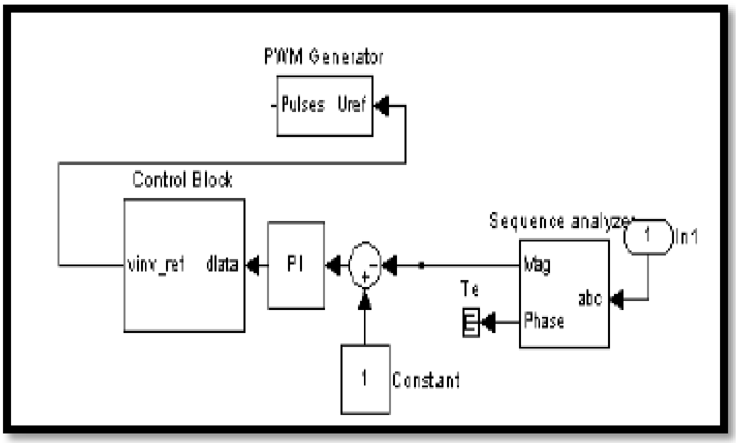

Figure-2 shows the block diagram of Controller system

The controller system is partially part of distribution system. Proportional-integral controller (PI Controller) is a feedback controller, which drives the system to be controlled with a weighted sum of the error signal (difference between the output and desired set point) and the integral of that value. In this case, PI controller will process the error signal to zero. The load r.m.s voltage is brought back to the reference voltage by comparing the reference voltage with the r.m.s voltages that had been measured at the load point. It also is used to control the flow of reactive power from the DC capacitor storage circuit. PWM generator is the device that generates the Sinusoidal PWM waveform or signal. To operate PWM generator, the angle is summed with the phase angle of the balance supply voltages equally at 120 degrees. Therefore, it can produce the desired synchronizing signal that required. PWM generator also received the error signal angle from PI controller. The modulated signal is compared against a triangle signal in order to generate the switching signals for VSC valves.

V. PROPOSED METHODOLOGY

A D-STATCOM is a shunt device that regulates the system voltage by absorbing or generating reactive power at a point of coupling connection. The schematic diagram of a DSTATCOM is shown in Fig 3. The D-STATCOM is a solid state DC/AC power switching converter that consists mainly of a three-phase PWM voltage source converter (VSC) bridge having six IGBTs with associated anti-parallel diodes. It is connected to the distribution network via the impedance of the coupling transformer. A DC-link capacitor provides constant DC link voltage.

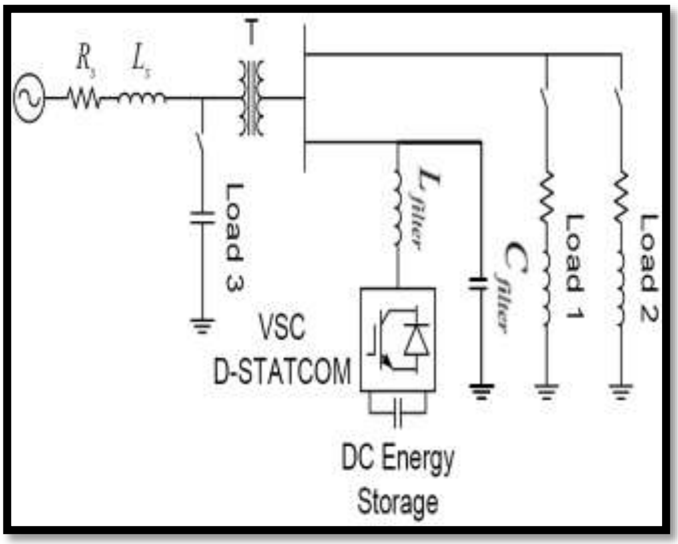

Fig-3 Simplified power system equipped with a D-STATCOM

The output voltage of the D-STATCOM is generated by a DC/AC voltage source converter operated from an energy storage capacitor. From the DC input voltage, provided by a charged capacitor, the converter produces a set of controllable three-phase output voltages at the frequency of the AC power system. Each output voltage is in phase with and coupled to the corresponding AC voltage via coupling reactance. By varying the magnitude of output voltage produced, the reactive power exchange between D-STATCOM and AC system is controlled. If the amplitude of output voltage is increased (or decreased) above the AC system voltage, the converter generates (or absorbs) reactive power for the AC system. DSTATCOM 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). It gives faster responses and can produce reactive power at low voltage. Also it does not require thyristor-controlled reactors (TCR) or thyristor-switched capacitors (TSC) that normally produce low order harmonics.

VI. CONTROL STRATEGY

A. Instantaneous Power Theory:-

As the name implied, the instantaneous power theory is based on a definition of instantaneous real and reactive powers in time domain. It is very useful not only in the steady-state but also in the transient state analysis for both three-phase systems with or without a neutral conductor. To illustrate the theory, let consider a set of instantaneous three phase quantity, for example Va, Vb and Vc. It starts with transforming a set of three-phase variables in the abc into αβ0 coordinates. This transformation is so-called as the Clark transformation as described follows.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \text{......(1)}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad \text{... (2)}$$

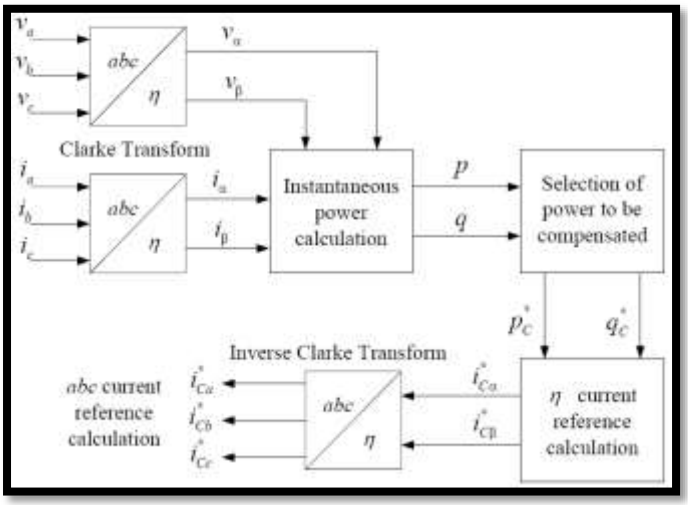

Fig. 4. Control block of shunt current compensation based on the instantaneous power theory

VII. CONCLUSION

This paper presents a modified control scheme to compensate a distribution feeder loading with non-linear loads. The compensation consists of three main objectives that are i) regulation of real powers delivering to loads, ii) regulation of DC link voltage to ensure PWM converter operation, and iii) correction of power factor. Modification of the control scheme made in this paper is to add the reactive power regulation into the control loop. With zero reactive power reference, unity power factor can be achieved. As a result, the modified control scheme can regulate DC link voltage and real power delivery at specified level while reactive power drawn from the load was cancelled by that injected from D-STATCOM.

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