A 24-pulse STATCOM Simulation model to improve voltage sag due to starting of 100 HP Induction-Motor

Mr. Ajay Kumar Bansal[1] Mr. Govind Lal Suthar[2] Mr. Rohan Sharma[3]

1 Associate Professor, Department of Electrical Engineering, Poornima College of Engineering, Sitapura Jaipur (Rajasthan)-302022.

2 M.Tech POWER SYSTEM(pursuing), Department of Electrical Engineering, Poornima College of Engineering, Sitapura Jaipur (Rajasthan)-302022.

3 M.Tech POWER SYSTEM(pursuing), Department of Electrical Engineering, Government Engineering College, Bikaner (Rajasthan)-334001

Abstract

A simulation model of static compensator (24-p STATCOM) has been constructed on matlab/simulink software to examine its capability for voltage sag mitigation This paper describes the performance of a Flexible Alternating Current Transmission Systems (FACTS) device, namely, STATic synchronous COMpensator (STATCOM) based on 24-pulse Voltage Source Converter (VSC), for the mitigation of voltage-dip caused by the starting of a 100 HP high power induction motor. It improves the voltage profile feeding to a high power induction motor at starting by injecting a controllable current to the supply line. Its capability to compensate reactive power to the system when the voltage dip occurs due to starting of 100 HP power induction motor load is described.

24-pulse VSC- based STATCOM and implemented it into a power-system consist a 100 HP power induction motor in MATLAB Simulink environment. The results show that the fast response and the STATCOM capability to for mitigate voltage sag.

Keywords

Voltage-dip mitigation, Static Synchronous Compensator, multiple-pulse Voltage Source Converter, Voltage Injection Capability, Reactive Power Compensation, Harmonic Analysis

I INTRODUCTION

Power quality is a quite broad concept, summarizing different electrical power characteristics. Ideally, the delivered power should have perfect current and voltage wave shapes and hundred percent reliable. Over the last decade the power quality issue has become a matter of growing concern. There are several causes that have initiated and later stimulated this concern however one other most important cause is the growing sensitive loads, (eg. Industrial plants) that use power electronics as a means of modernizing their manufacturing processes [1]. As the sensitivity of the load increases the costs associated with the damage caused by voltage sags increase too.

One of the most important voltage-related problems is voltage sag. Voltage sag is an rms reduction in the ac voltage at the power frequency, for duration from a half-cycle to a few seconds [2]. Magnitude and duration are its two most important characteristics. There are two causes of voltage sag, normally line to ground faults and motor starting. Line to ground faults result in voltage sags that are shorter (from approximately 10 ms) and have magnitudes down to 10%. Motor starting produces sags having smaller magnitudes but they last longer up to 600ms.

This paper focused on voltage sag caused by starting of induction motor. The induction motor is subjected to the voltage sag slow down but usually do not stop operating, if not tripped by contactors. Problems can occur due to torque oscillations that can be associated with very deep sags or to tripping of over current relays, due to the high current drawn by the motor.

Voltage dips are huge problem for many industries and they have been found especially troublesome because they are random events lasting only a few cycles. However, they are probably the most pressing power quality problem facing many industrial customers today [5]. The concern for mitigation of voltage dip has been gradually increasing due to the huge usage of sensitive electronic equipment in modern industries. When heavy loads are started, such as large induction motor drives, the starting current is typically 600% to 700% of the full load current drawn by the motor. This high current cause dips in the voltage during starting intervals, because there is a lot of voltage drop across the distribution conductor. Since the supply and the cabling of the installation are dimensioned for normal running current and the high initial current causes a voltage dip. This voltage dips are short duration reductions in rms input voltage as shown in Fig.1 [4]. It is specified in terms of duration and retained voltage, usually expressed as the percentage of nominal rms voltage remaining at the lowest point during the dip. Another reason for high starting current is the inertia of the load as high starting torque is required to start the high inertia loads, which can be obtained by using high starting current. This problem becomes more severe at peak loading time. This is due to the fact that at peak loading time the voltage of the system is less than the rated voltage.

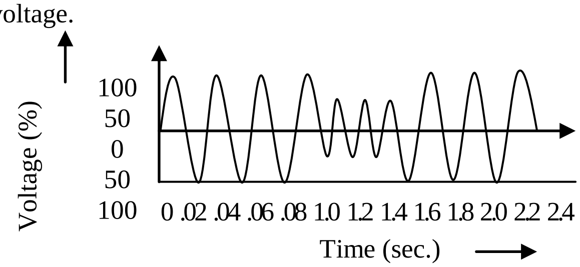


Fig.1 A Typical Voltage Dip

As the STATCOM is a solid-state voltage source converter coupled with a transformer, tied to a line can injects reactive current or power to the system to compensate the voltage-dip. The Voltage-Source Converter (VSC) is the main building block of the STATCOM. It produces square voltage waveforms as it switches the direct voltage source ON and OFF. The main objective of VSC is to produce a near sinusoidal AC voltage with minimum waveform distortion or excessive harmonic content. This can be achieved by employing multiple-pulse converter configuration [6]. A 24-pulse GTO based VSC can be constructed using two (12-pulse GTO based) converters, shifted by 15° from each other. Srinivas K. V. et al in [8] developed a three-level 24-pulse STATCOM with a constant dc link voltage and pulse width control at fundamental frequency switching, validated the inductive and capacitive operations of the STATCOM with satisfactory performance

II THE STATCOM

The STATCOM is a VSC-based shunt device. It is made up of a voltage source converter (VSC), DC capacitor, shunt transformer and a controller associated with VSC as shown in Fig.2. In general, STATCOM is capable of generating or absorbing independently controllable real and reactive power at its output terminals, when it is fed from an energy source or energy storage device at its input terminal. If there is no energy storage device coupled to the DC link and the losses are neglected, then shunt converter is capable of absorbing or generating reactive power only. Functionality, from the standpoint of reactive power generation, their operation is similar to that of an ideal synchronous machine whose reactive power output is varied by excitation control.

A. OPERATING PRINCIPLE

In general, STATCOM is employed to generate or absorb reactive power. The active power generation or absorption capability of the STATCOM is normally used under special circumstances such as to enhance the steady state and transient voltage control, to improve the sag elimination capability.

The STATCOM basically consists of a step-down transformer with a leakage reactance, a three-phase thyristor based voltage source inverter (VSI) and a DC capacitor. A basic structure of the STATCOM is shown in Fig 2. The AC voltage difference across the leakage reactance produces reactive power exchange between the STATCOM and the power system, such that the AC voltage at the bus bar can be regulated so as to improve the voltage profile of the power system, which is the primary duty of the STATCOM. However, for instance, a Secondary damping function can be added into the STATCOM for enhancing power system oscillation stability

A STATCOM is a controlled reactive-power source. It provides the desired reactive power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage-source converter (VSC). The reactive power exchange of STATCOM with the AC system is controlled by regulating the output voltage amplitude of voltage source converter.

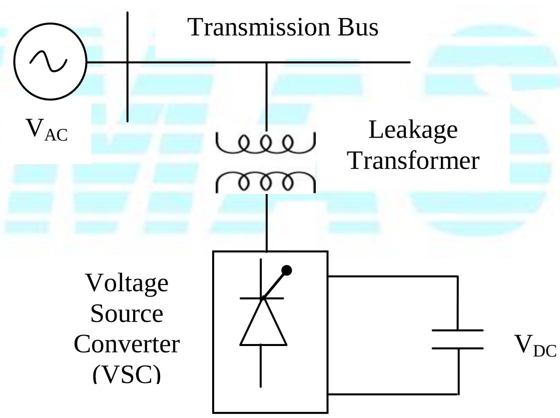


Fig.2. Voltage Source Converter based STATCOM

If the amplitude is increased above that of the AC system voltage, then the current flows from the STATCOM to the AC system and the device generates capacitive reactive power. If the amplitude is decreased to a level below that of the AC system, then the current flows from the AC system to STATCOM. The amount of type (capacitive or inductive) of reactive power exchange between the STATCOM and the system can be adjusted by controlling the magnitude of STATCOM output voltage with respect to that of system voltage. The reactive power supplied by the STATCOM is given by:

$$Q = \frac{V_{STATCOM} - V_S}{X} * V_S \qquad (1.1)$$

Where Q is the reactive power, $V_{STATCOM}$ is the magnitude of STATCOM output voltage, V_S is the magnitude of system voltage and X is the equivalent impedance between STATCOM and the system. When Q is positive the STATCOM supplies reactive power to the system. Otherwise, the STATCOM absorbs reactive power from the system. The DC capacitor voltage controls the output voltage of voltage source converter. The output voltage of voltage source converter can be lead or lag with respect to AC system voltage by increased or decreased DC capacitor voltage respectively. When the voltage source converter voltage leads the bus voltage, the capacitor supplies real power to the system, acting as capacitive power source. On the other hand, when the voltage-source converter voltage lags the bus voltage, than the capacitor charged by consuming real power from the AC system having inductive reactance property, so that act as an equivalent inductor as illustrated by the phasor-diagrams shown in Fig. 3.

When the STATCOM output voltage ($V_{STATCOM}$) is lower than the system bus voltage (V_S), the STATCOM acts like an inductance absorbing reactive power from the system bus. When the STATCOM output voltage ($V_{STATCOM}$) is higher than the system bus voltage (V_S), the STATCOM acts like a capacitor generating reactive power to the system bus. In steady-state operation and due to inverter losses, the system bus voltage (V_S) always leads the converter ac voltage by a very small angle to supply the required small active power losses.

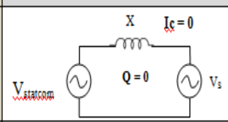
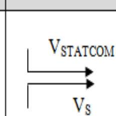
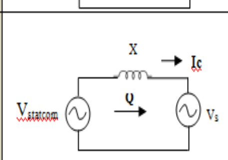
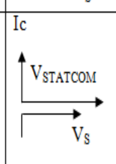
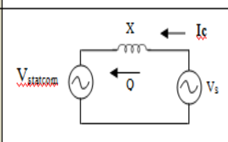
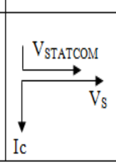
Mode	Equivalent Circuit	Phasor Diagram	Description
No Load Operation			$V_{STATCOM} = V_S, I_C = 0$. No reactive power exchange.
Capacitive Operation			$V_{STATCOM} > V_S$, Ic leading. The STATCOM will function as a capacitor whose capacitive-reactance is continuously controlled.
Inductive Operation			$V_{STATCOM} < V_S$, Ic lagging. The STATCOM will function as a reactor whose inductive-reactance is continuously controlled.

Fig. 3 STATCOM operation

B. SIMULLATION MODEL

The complete model of voltage-dip mitigation by 24-pulse STATCOM during the starting of an induction motor simulated is as shown in Fig.4. The design of the system is according to the line voltage and 100 HP, 460V and 50 Hz asynchronous motor under consideration.

III SIMULATION RESULTS

The complete model with the voltage-dip caused by the starting of a squirrel-cage induction motor of 100 HP, 460V and 50 Hz is simulated first without STATCOM. A 3-phase breaker is chosen to start the induction motor and it is set to close at an instant t = 0.2 sec. The 3-phase voltage source with a small resistance in series with each phase is taken to implement a practical supply system. The measurement of the system voltage and supply current is provided by the 3-phase V-I measurement block and the stator current, rotor current, speed of rotor and electromagnetic torque are measured at bus-selector available in asynchronous-motor block. The system-voltage and current of all three phases during the motor-start at t = 0.2 sec and rotor current is as shown in Fig.5. The type of simulation used in *powergui* to simulate the problem is *continuous* with variable step-size and the solver chosen is ode23tb (stiff/TR-BDF2).

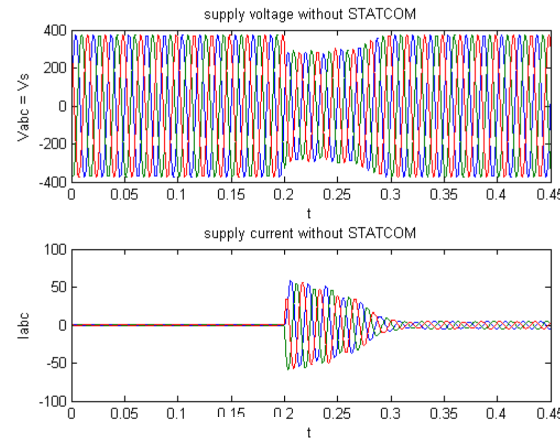


Fig.5 (a) System Voltage and Current during the Starting of the Motor

Now, after the implementation of the STATCOM consisting 24-Pulse three-level converter, the STATCOM voltage and current delivered at load terminal are as shown in Fig.6 below. The capacitors employed in the STATCOM act as a variable DC voltage source. Here, the capacitors modelled and simulated are initially charged (initial conditions) by the system voltage. The variable amplitude voltage produced by the inverter is synthesized from the variable DC voltage.

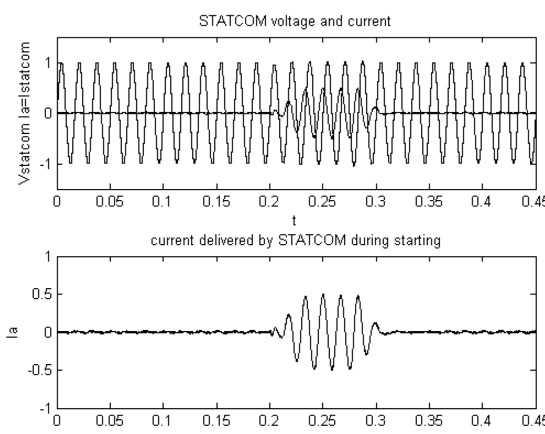


Fig. 6 STATCOM Voltage and Current Delivered during Voltage-Dip

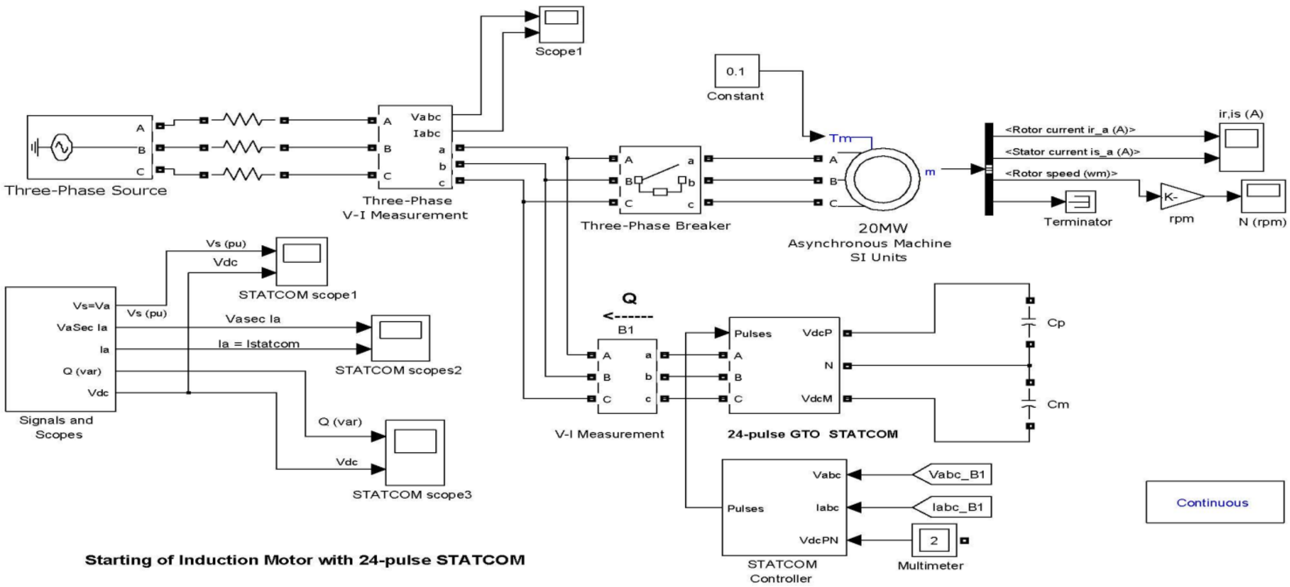


Fig.4 Implementation of the 24-Pulse VSC-based STATCOM

As soon as the motor is started at t=0.2sec, the dip in the rms voltage introduced is mitigated well. A slight voltage-dip, ΔV, is there even after the implementation of the STATCOM as shown in Fig.7. It is seen from the response that the current is lagging by an angle of 90° from system voltage i.e. a reactive power is fed to the system by the STATCOM during voltage-sag. The FFT analysis of STATCOM's output clearly shows the 24-pulses of a cycle of output voltage containing a fewer harmonics (THD =7.79%) as shown in Fig.8 below. It is also seen that only 24n±1 harmonics are present in the voltage as expected.

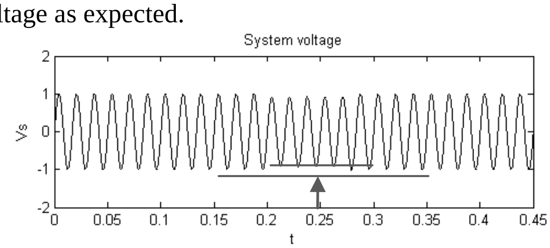
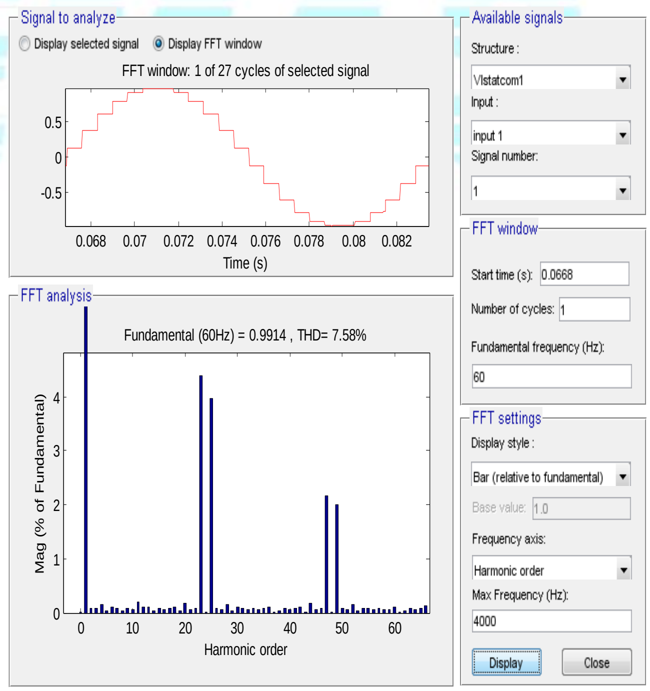


Fig.7 System Voltage with 24-Pulse STATCOM

IV CONCLUSION

The results shows that whenever an induction motor is started, a voltage-dip of up to 25% is there in the system-voltage as shown in Fig.5 (a).Now, as soon as the multiple-pulse STATCOM is implemented into the system and comes under action, the voltage-dip, caused by the starting of the motor at t = 0.2sec onwards for 4-5 cycles, is mitigated well as the comparative results shows in Fig.5 and Fig.7 above. A slight voltage-dip, ΔV only is found after the implementation of the STATCOM as shown in Fig.7. The results also show that the voltage fed



by the 24-pulse STATCOM adds a fewer harmonics into the system having THD =7.79%.

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