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A Method for Design of DSTATCOM Fast Acting DC Link Voltage Controller

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ABSTRACT

This paper explains the detailed design analysis and simulation of Distribution Static Synchronous Compensator (DSTATCOM) in terms of compensated to be in command of Voltage Source Converter (VSC) input voltage, recompose of reactive power and enhancement of power factor for radial distribution system of 11kV/415V, 800 kW rating. The model has been simulated and tested in Matlab/Simulink using simscape tool block set version of Matlab R2019a. The same is achieved using DSP TMS 320 F 2812, a 32-bit processor that is programmed with CCS V 6.1 software. The methods are Back Propagation Control Algorithm (BPCA), and Synchronous Reference Frame Theory (SRFT). BPCA is based on the elementary extracted biased value of Reactive Power (Q) and Active Power (P) components of load currents. These current values are necessary for the reference source current evaluation. The reference source currents are evaluated from the available source currents to generate firing pulses for the SRFT and BPCA. SRFT is based on the transformation of synchronously rotating load currents in direct axes and quadrature axes frame. BPCA and SRFT based DSTATCOMS are simulated for linear and nonlinear load circumstances.

Keywords: *FACTs Device, DSTATCOM, VSC, PCC, BPCA, SRFT.*

1. INTRODUCTION

Reactive power control is very important present days due to more nonlinear load are connected to Electrical Distribution System (EDS), so that the system gets polluted due to the nonlinear load on the load side [1]- [4]. The control of reactive power enables the system to get better power factor (PF) this leads to reduction in line current follow-on in proper consumption of distribution transformer and reduced power bills. The excessive reactive power demand and harmonics in the system due to non liner and variable loads reduces the real power flow of the distribution system. To overcome these problems, in this paper fast acting voltage source converter (VSC) input voltage control and reactive power control algorithms are studied and finally analyzed the best suitable control methodology is proposed to DSTATCOM for reactive power compensation. By these controllers the DSTATCOM would generate under voltage or over voltage at PCC this lead to lagging or leading power factor at the bus. To stay away from problems connected with lagging and leading power factor and minimized harmonics in the system. The power factor can be maintained at the desired level irrespective of system terminal voltage [5]. These loads can be grouped as resistive type, inductive type and some harmonic injecting variable type of non linear loads. This paper, deals with two major types of controls as mentioned in the above.

The static synchronous compensator is connected parallel to a 3- phase load side, the connected source resistance and reactance which are shown in Fig. 1. The controller control performance depends upon the correctness of reactive power injection at the bus. The tuned values of coupling reactor (Lf) are connected at the ac output of the voltage source converter. The controller injects the required amount of currents to control the reactive power at the bus. The rating of injecting current at the bus decides the rating of the VSC. The choice of VSC input voltages, rating of coupling capacitor value, interfacing reactor value, are very important for controlling of VSC converter as a DSTATCOM control mode.

2. DSTATCOM MODELLING

The DSTATCOM control in this paper can be divided in to two types they are SRFT and BPCA, these controllers are computer modeled using Matlab software, and the results are presented with fast acting and normal PI control strategy. The Synchronous Reference Frame Theory (SRFT) control methodology can be adopted from [4] - [6]. In this SRFT the line currents are transposed to d, q quantities and using LP filter and gains the equivalent direct axis real and reactive currents can be calculated, from this the reactive current requirement can be estimated. Simultaneously the DC side voltage control also can be

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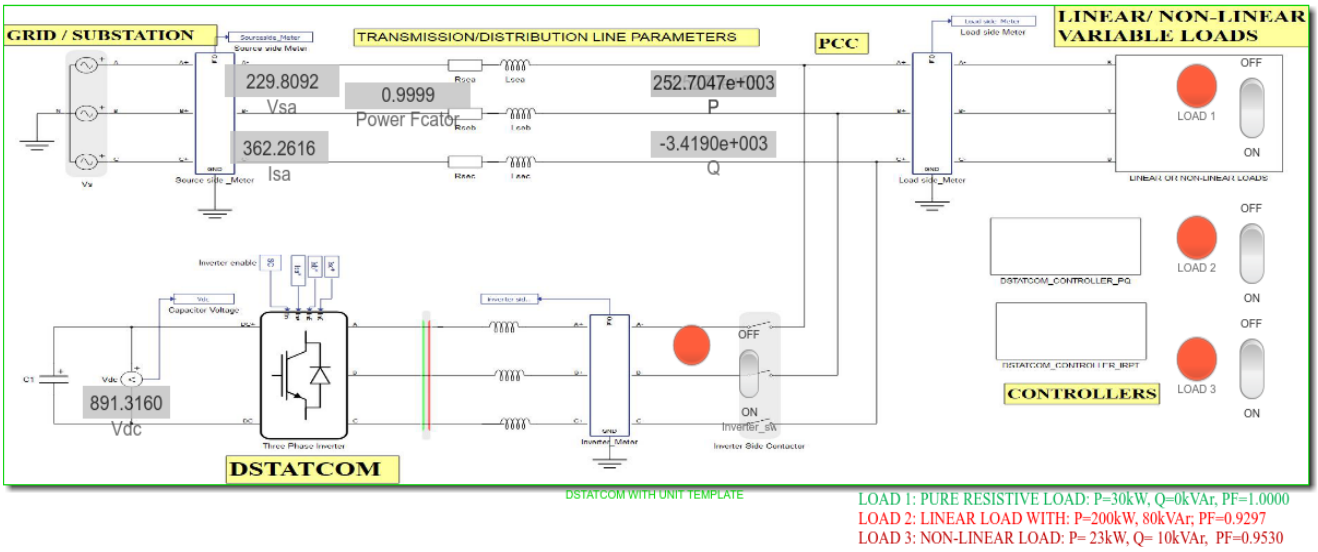

Fig.1. DSTATCOM simulated model in MATLAB.

done using dc side PI controller and ac side voltage can be controlled using the ac side PI controller from this two ac and dc side PI controller the reference supply side direct axis and quadrature axis currents can be estimated. These currents can again converted using reverse conversion of d, q to a, b, and c then after we will estimate the reference source currents. By taking actual line currents subtracting from reference we will be able to generate actual reference control signal currents this complete process as shown in Fig. 2.After generating the actual reference currents using sine PWM control generate the firing pulse for the turn on and turn off of the inverter stack. With this the SRF control will be able to control the reactive power in both linear and non linear loads the corresponding conversion mathematical equations can be taken from reference [7] - [11].

2.1 Back Propagation Control Algorithm (BPCA)

BPCA preparation algorithm is used mainly for the reference currents estimation through weighted source currents. The load terminal active and reactive power current components as shown in Fig. 3. In this controller, the (Vsa, Vsb, and Vsc) & (isa, isb, and isc) are the phase voltages and currents are taken from converter connected terminals. Load drawing current components of (iLa, iLb, and iLc), and VSC input voltage (V_{DC}), are required for the reference source currents (i*sa, i*sb, and i*sc) [11]. Two primary algorithms are used for controlling they are feed forward, and the Back Propagation error method. The estimation of different control parameter is given as mentioned in reference [7]-[8].

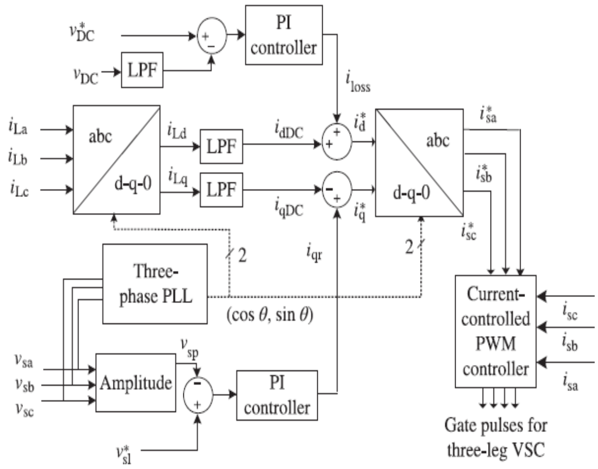

Fig. 2. Block diagram of SRF control.

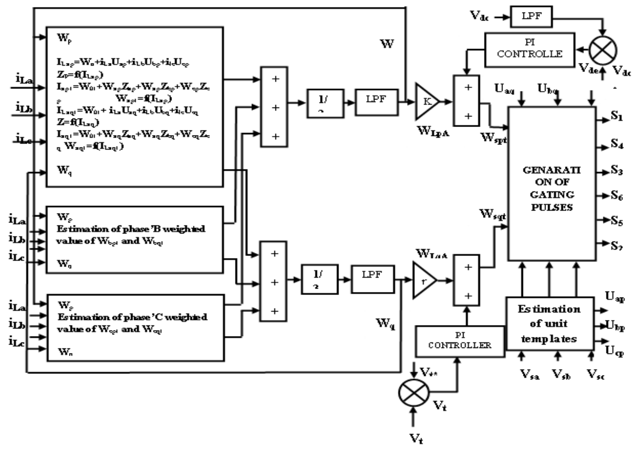

Fig. 3. Block diagram of back propagation control algorithm.

2.2 VSC input voltage control methods.

To maintain the constant input voltage of VSC a conventional proportional plus integral controller and a

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fast acting closed loop proportional plus integral controller are used the control of the VSC input voltage is expressed as

$$u_c = K_p \times (v_{dcref} - v_{dc}) + K_i \int (v_{dcref} - v_{dc})$$

The general PI controller used for maintaining the VSC input voltage as shown in Fig. 4.

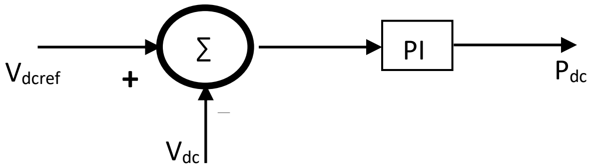

Fig. 4. Conventional DC Link Voltage Controller.

$$p_{dc} = K_p \times (v_{dcref} - v_{dc}) + K_i \int (v_{dcref} - v_{dc})\, dt$$

To overcome the disadvantages of the conventional controller, an energy-based dc-link voltage controller is shown in Fig. 5.

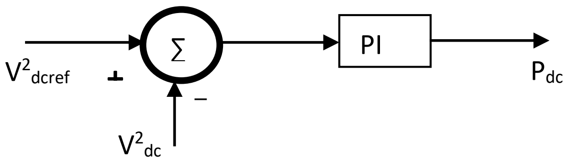

Fig. 5. Fast Acting VSC source voltage controller.

The energy required by the VSC input side a electrolytic capacitor is connected to charge from actual voltage to that of reference value is given as

$$w_{dc} = 0.5 * C_{dc} * (v_{dcref} - v_{dc})$$

The total DC power required by the VSC source capacitor is computed as follows

$$p_{dc} = K_{pe} * (v_{dcref}^2 - v_{dc}^2) + K_{ie} \int (v_{dcref}^2 - v_{dc}^2)\, dt$$

3.3. Experimental setup specifications

The below mentioned parameters are used for simulation as well as hardware model.

- System capacity = 800 kW
- The main line is connected to two transformers - 500 kVA and 250 kVA.
- Total reactive demand for the system is approximately 300 kVAr.
- Existing systems are provided with two 150 kVAr power factor correction (PFC) banks.
- A 30 kVAr D-STATCOM is proposed for power factor correction. (riding over existing 300 kVAr PFC banks)
- AC supply source: 3-Phase, line voltage of 415 V, 50 Hz.
- The source impedance of Rs = 0.05 Ohm and Ls = 2.1 mH. (these values are calculated from cable ratings)
- Loads: Linear / Non linear Loads
- Load Types: 1. Different types of Motor loads, UPS, Fan and Lighting load of an educational institute.
- Rating of voltage source converter = 30 kVA.
- Inverter switching frequency = 2.5 kHz.
- VSC input reference as 700 V.
- DC bus Capacitance (Cdc)=4700 µf @ 450V Series connected = 900V.
- Interfacing inductor (Lf) = 3.6395 mH
- Gains of VSC bus voltage PI controller: kid=0.9 and kpd = 3.1.
- Gains of source voltage PI controller: Kpt=2.95 and Kit=4.

3. SIMULATION RESULTS

In this section, the system is modeled as Control of DSTATCOM in SRFT & BPCA with and without fast acting VSC PI controller. The detailed result analysis for different load conditions with and without DSTATCOM for fixed and varying loads was analyzed in this section.

Case (a) Without Controller

In this section the system is simulated without controller with a load of quarter, half, ¾Th and full load and the obtained results of different parameters are as shown in below Table I.

Table-I.

TYPE OF LOAD (RL)	QUARTER LOAD	HALF LOAD	¾Th LOAD	FULL LOAD
SOURCE CURRENT (A) (RMS)	299	617	982.2	1357
ACTIVE POWER (kW)	200	400	600	800
REACTIVE POWER (kVAr)	79	192	372	558
POWER FACTOR	0.93	0.9	0.85	0.82

Varying load of all above four linear loads, switching at different time period with the control of three phase breakers, Base load is on throughout the whole simulation time, i.e. 2 seconds, Base load: 600 kW, 372 kVAr 0.85 power factor lagging. Load 1: 800 kW, 558 kVAr, 0.82 power factor lagging, Duration 0.4 seconds to 1 seconds, Load 2: 400 kW, 192 kVAr, 0.9 power factor lagging, Duration 0.7 seconds to 1.2 seconds Load 3: 200 kW, 79 kVAr, 0.93 power factor lagging, Duration 1.3 seconds to 1.7 seconds These variations as shown in Fig. 6.

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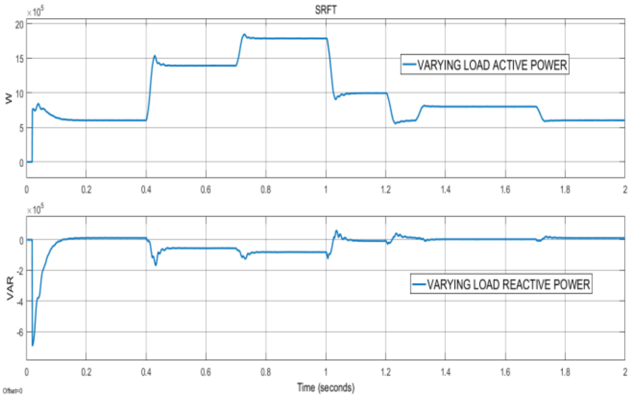

Fig. 6. Varying load Active and reactive power in SRFT.

Case (b) With Controller.

The DSTATCOM controller is executed by using DSP TMS 320 F 2812, it is directly connected to personal computer (PC) with JTAG Emulator, and the programming is done through CCS V 6.1. The signals of current and voltage sensors the reactive power is calculated from obtained and calculated using DSP programming, after that using the theories mentioned earlier, like SRFT using gating signals the inverter stack should be fired and required amount of reactive power is injected in to the bus and maintain the system power factor to unity. After compensation using DSP with SRF controller the main substation electricity energy meter shows unity power factor as shown in Fig. 7. The complete hard ware DSTATCOM model as shown in Fig. 8.

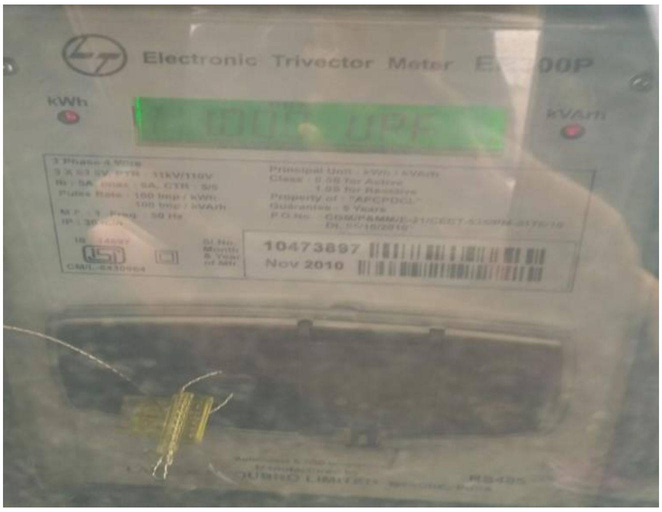

Fig. 7. TSSPDCL Substation Energy Meter Showing UPF.

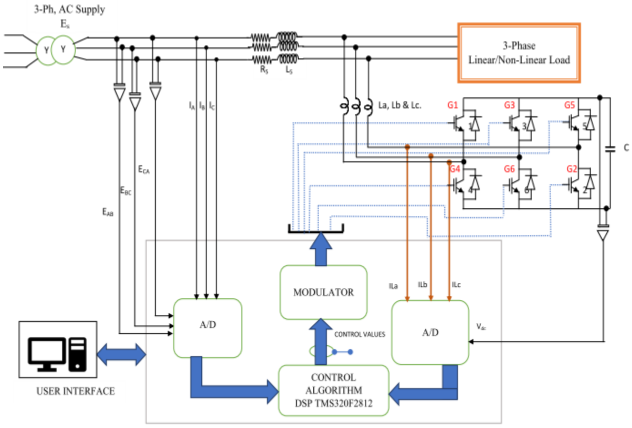

Fig. 8. Hardware model of SRFT control.

Fast acting PI Controller has lesser rise time, and improved stability, lesser ripples when compared to basic proportional plus integral controller. The response time of Fast acting PI controller is better than that of conventional PI controller. The different load variations have been considered for implementing this improved PI controller. Quarter Load has been considered for that, the Fig. 9. Shows the comparison of two different DC link voltage applied on same load for SRFT, and the response times for conventional PI controller is 507 milliseconds and that of fast acting PI controller is 195 milliseconds. The reactive power injections of 75% of load and full load as shown in Fig. 10. The corresponding variable load real and reactive powers are shown in Fig.11. The variations of the angle between voltage and current of phase A with a half and quarter load without controller as shown in Fig. 12. Clearly it is showing that without controller the phase angle between voltage and current of phase A, the power factor of the different loads shown in Table II. The correction of power factor and the zero phase angles are shown in Fig. 13 and Fig. 14.

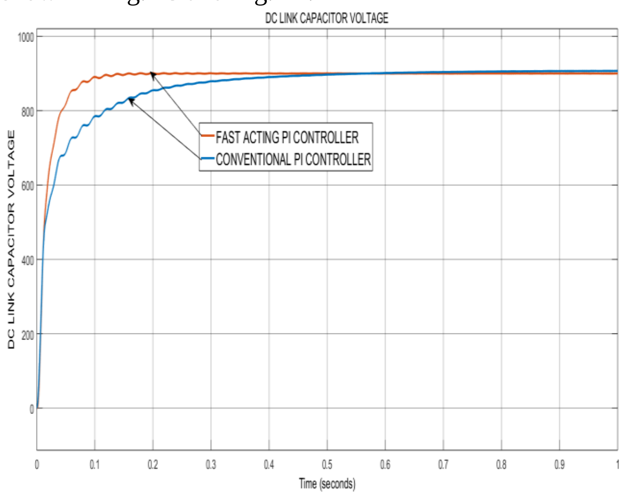

Fig. 9. Conventional and fast acting PI controller.

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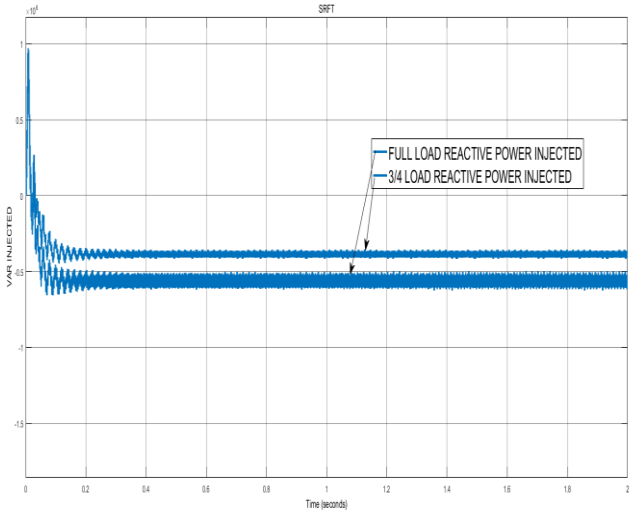

Fig. 10. Reactive Power Injections at PCC for 3/4Th and Full load Conditions.

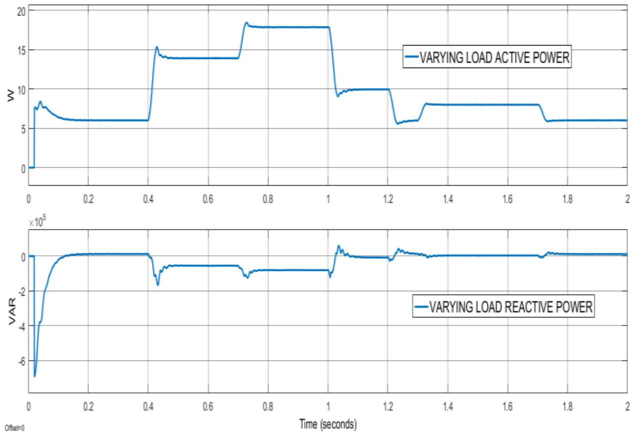

Fig. 11. After correction BPCA real and reactive powers on the bus.

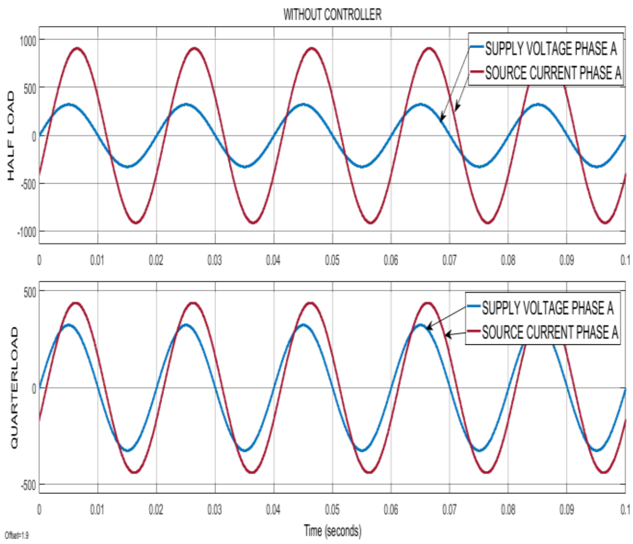

Fig. 12. Voltage and current wave forms of Phase a shows power factor angle.

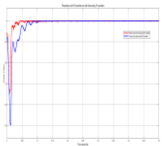

Fig. 13. Power factor of varying load with controller showing UPF.

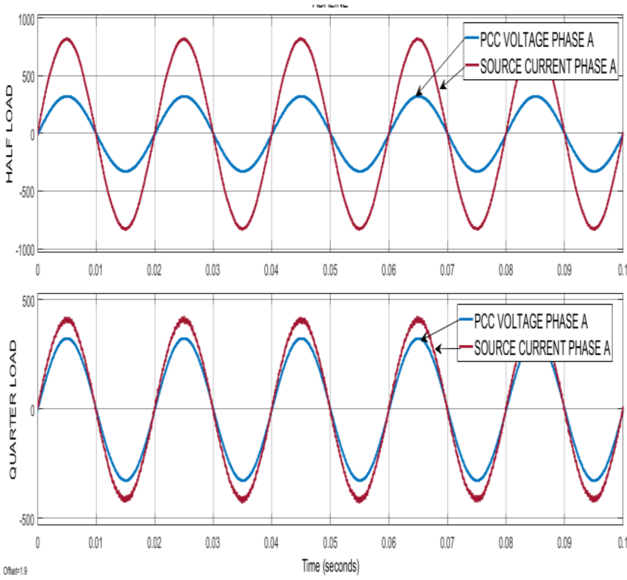

Fig. 14. Wave form of the voltage and current of phase a with BPCA controller.

For nonlinear load the control of reactive power, the load modeling and the SRF control is implemented in the CCS V6.1, and the DSP TMS 320 F2812 32 bit controller is used for control, the corresponding control firing pulses are observed in the RIGOL 4-Channel oscilloscope as shown in Fig. 15. The reactive power injection done in the system PF correction is happened and the unity power factor is recorded in multifunctional energy meter and as shown in Fig. 16.

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Fig.15. Firing pulses observing at one of the instants in the oscilloscope.

Fig. 16. Multi function energy meter shows power factor to unity on the bus.

Power factor and correction time of different Load conditions with different controllers are shown in Table-II.

TABLE II

Loads	Quarter Load (200 kW)		
Methods	Without Control	SRFT	BPCA
I_S(RMS)	299	278.39	278.35
Response time(ms)	------	29	22
PF	0.93	0.9994	0.9996
Loads	Half load (400 kW)		
I_S(RMS)	617	556.77	556.69
Response time(ms)	----	71	46
PF	0.90	0.9995	0.9996
Loads	¾ th load (600 kW)		
I_S(RMS)	982	1193.93	1193.84
Response time(ms)	---	50	44
PF	0.85	0.9998	0.9999
Loads	Full load (800 kW)		
I_S(RMS)	1357	1113	1113.01
Response time(ms)	----	49	44
PF	0.82	0.9999	0.9999

4. CONCLUSIONS

In this paper an 11kv / 415v, 800 kW, 3-phase radial distribution system (RDS) was studied and the two DSTATCOM controllers have been simulated in Matlab R2019 a. The fast acting voltage source converter input voltage is controlled using a modified PI controller has been implemented and executed successfully. For the analysis the parameters considered are source current, coupling voltage, Active power, injected reactive power, response time (milliseconds) and power factor for linear and nonlinear loads. For comparison a hardware model done with SRFT theory in DSP TMS 320F2812 for nonlinear load, the power factor maintained unity with the help of DSTATCOM. The VSC gate firing pulses are generated using SPWM technique. From the simulation and Hardware results it can be concluded that SRFT fast PI is little bit slower responsive than the BPCA fast PI controller.

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