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A Case Study of Power Factor Improvement on Village Loads

Dr.P.Santosh Kumar Patra[1], Dr.N.Ramchandra[2],

[1]Principal & Professor in Dept. of Computer Science and Engineering, St. Martin's Engineering College, Secunderabad, Telangana, India

[2]Professor in Dept. of Electrical and Electronics Engineering, St. Martin's Engineering College, Secunderabad, Telangana, India

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Abstract - *The main aim of this paper is to improve the power factor by developing DSTATCOM with Instantaneous Unit Template algorithm. In this paper a particular zone in Chandragunda village, Warangal district, Telangana is considered for case study of power factor in distribution line. It is observed that the most common problem in village is the interruption of power supply due to frequent tripping of distribution transformer. The causes for frequent tripping of distribution transformer are large reactive loads, low power factor and overloading. The large consumers with low power factor also being charged penalty by the electricity board. Therefore power factor improvement plays a vital role for efficient system operation and reducing electricity consumption cost. In this paper a test distribution system connected to four induction motors of different ratings and rectifier loavd is considered. In order to improve the power factor DSTATCOM with instantaneous unit template algorithm is connected in parallel with the feeder and simulated for simulation results.*

Key Words: Power factor, Harmonics, Reactive Power DSTATCOM, Voltage

1. INTRODUCTION

In villages the most of the loads connected to the distribution lines are inductive loads. Especially in agriculture induction motors are used for irrigation purpose. It requires more reactive power for magnetization and increases the apparent power requirement in distribution line which reduces the power factor. Due to low power factor the induction motors draws high currents greater than the pre outage current from distribution transformer causes overloading. It is one of the major causes for frequent tripping of distribution transformer in villages. Therefore it is essential to improve the power factor at load ends.

In order to improve the power factor the FACTS device like DSTATCOM, a shunt compensator is connected at load end [1]. It controls the reactive power flow in the distribution line by injecting compensator currents to improve the performance of the system. The building block of the DSTATCOM is control algorithm which plays a vital role in its principle of operation [2-3]. It controls the compensator voltage by controlling the firing pulses of IGBT based Voltage Source Inverter (VSI). Based on compensator voltage and grid voltage it acts either a source or sink of reactive power. If the compensating voltage is greater than grid voltage then it acts as source of reactive power and works in capacitive mode to improve the power factor. In this paper a particular zone in chandragunda village Warangal district is chosen for case study of power factor in distribution line. In this village agriculture is the major occupation and uses the induction motors for irrigation. All the induction motors are connected to the feeder of the distribution transformer. The most common problem noticed is the interruption of power supply due to frequent tripping of distribution transformer. The causes for frequent tripping are large reactive loads, low power factor and overloading. Therefore in order to control the reactive power flow and for power factor improvement a pole mounted DSTATCOM is proposed. It should be connected at load end to improve the performance of the system. A novel control technique i.e., the instantaneous unit template algorithm is proposed to control the operation of the DSTATCOM. This algorithm uses unit templates and instantaneous powers for the extraction of reference currents which reduces the execution time. Hysteresis current controller is used to generate firing pulses for IGBT based VSI. For simulation a test distribution system which is connected to four induction motors of different ratings and a rectifier load is considered. The system is simulated with and without DSTATCOM and observed the results. The next section discusses about power factor and power factor correction methods.

2. POWER FACTOR CORRECTION

2.1 Power factor

Power factor is used to measure how effectively the electrical power is being used by the consumers. If it is less than one the electricity board has to supply more current to the consumers for a given amount of power use which increases the line losses. As a result they will charge penalty for large consumers having low power factor [4].

2.2 Power factor correction unit

It is important to identity most effective method to improve the power factor in feeders. The proposed and most effective method to improve the power factor in feeders is a pole mounted shunt connected DSTATCOM. The block diagram of DSTATCOM is shown in Fig.1

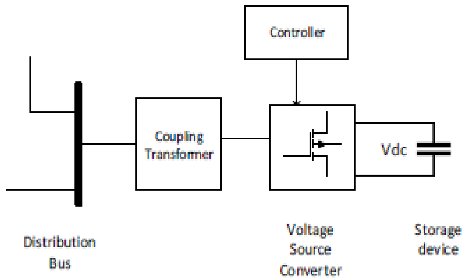


Fig.1. Block diagram of DSTATCOM

The building block of the DSTATCOM is control algorithm which controls the firing pulses of IGBT based Voltage Source Inverter (VSI). Many of the papers in the literature reported different control algorithms for DSTATCOM to improve the performance of the system are [5-10]:

- Instantaneous p-q theory
- Synchronous reference frame theory
- Unit template algorithm
- Deadbeat Predictive control

The instantaneous p-q theory is used to compensate Instantaneous reactive power and sinusoidal component of instantaneous active power in order to improve the power factor of the system [3-4]. The problem caused by voltage distortion in instantaneous p-q theory can be solved by using phase locked loop in synchronous reference frame theory [5]. The unit template algorithm uses unit templates for the extraction of reference currents instead of Phase locked loop reduces the execution time [6]. The deadbeat predictive control algorithm uses discrete modelling of the system to calculate reference currents in order to reach desired load current [7].

In this paper a novel control technique instantaneous unit template algorithm is proposed, it includes both the advantages of instantaneous p-q theory and unit template algorithm. It calculates unit templates and instantaneous powers for the extraction of reference currents. It also reduces the execution time and reactive power burden on DSTATCOM. The next section describes the proposed algorithm for DSTATCOM.

3. PROPOSED CONTROL ALGORITHM

3.1 *Instantaneous unit template algorithm*

This algorithm is used to calculate instantaneous active and reactive power based on the unit templates of load voltage and current to generate reference currents [5, 9]. The block diagram of instantaneous unit template algorithm is shown in Fig .2

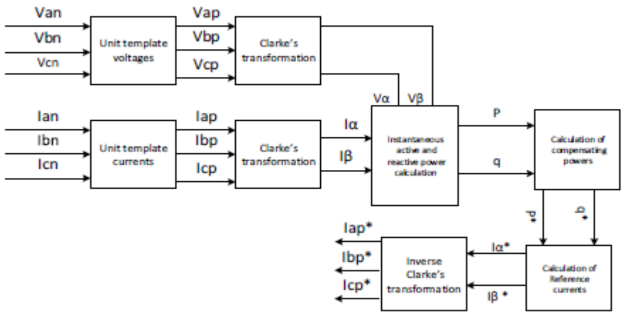


Fig.2. Instantaneous unit template algorithm

V_{an}, V_{bn}, V_{cn}, are the phase voltages at point of common coupling (PCC). The amplitude of the PCC voltage is

$$V_t = \sqrt{\frac{2}{3}(V_{an}^2 + V_{bn}^2 + V_{cn}^2)} \qquad (1)$$

The unit templates in phase with the PCC voltages are

$$V_{ap} = \frac{V_{an}}{V_t};\ V_{bp} = \frac{V_{bn}}{V_t};\ V_{cp} = \frac{V_{cn}}{V_t} \qquad (2)$$

These in phase unit templates are converted in to two variables using park's Clarke transformation in order to reduce the complexity of calculations

$$\begin{bmatrix} V_o \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} V_{ap} \\ V_{bp} \\ V_{cp} \end{bmatrix} \qquad (3)$$

Ian, Ibn, Icn, are the load currents flowing through the induction motors and the amplitude of the load current is

$$I_t = \sqrt{\frac{2}{3}(I_{an}^2 + I_{bn}^2 + I_{cn}^2)} \qquad (4)$$

These load currents are converted in to per unit values to make ease of calculations

$$I_{ap} = \frac{I_{an}}{I_t};\ I_{bp} = \frac{I_{bn}}{I_t};\ I_{cp} = \frac{I_{cn}}{I_t} \qquad (5)$$

These three variables are converted in to two variables using park's Clarke transformation in order to reduce the complexity of calculations

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} I_{ap} \\ I_{bp} \\ I_{cp} \end{bmatrix} \tag{6}$$

From (3) and (6) the instantaneous real and reactive powers are calculated

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{7}$$

For reactive power control in the distribution line the entire reactive power and ac component of the active power are taken as reference powers to calculate reference currents.

$$P^* = V_\beta \ I_\beta \tag{8}$$

$$q^* = V_\beta I_\alpha - V_\alpha I_\beta \tag{9}$$

From (8) and (9) the reference currents for the controller can be calculated

$$\begin{bmatrix} I_\alpha^* \\ I_\beta^* \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} -P^* \\ -q^* \end{bmatrix} \tag{10}$$

The reference currents are again converted back to three variables using inverse Clarke's transformation.

$$\begin{bmatrix} I_{ap}^* \\ I_{bp}^* \\ I_{cp}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_\alpha^* \\ I_\beta^* \end{bmatrix} \tag{11}$$

Then the reference currents are compared with load currents using hysteresis current controller to generate firing pulses for IGBT based VSI. This voltage appears across reactors, based on the comparison between grid voltage and compensator voltage the DSTATCOM controls the reactive power flow in the line to improve power factor.

4. TEST DISTRIBUTION SYSTEM

In chandragunda village, Warangal district, Telangana a particular zone is considered for case study of power factor in distribution lines. It is observed that in early morning and evening hours, all the induction motors connected to feeder are switched on at a time for irrigation due to which the transformer gets overloaded and reduces the power factor of the line. It is the main reason for frequent tripping of distribution transformer which leads to poor reliability in villages. Therefore in order to solve this problem a DSTATCOM should be connected at load end to improve the power factor is proposed.

For simulation a test distribution system connected to four induction motors of different ratings and a rectifier load is considered. The schematic diagram of test distribution line connected to different non-linear loads is shown in Fig. 3

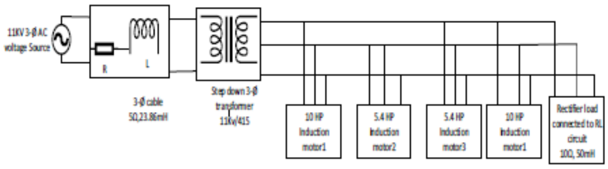


Fig.3. Distribution line without DSTATCOM

The test distribution system is designed in simulation similar to real distribution system to get an idea of the system operation without DSTATCOM. The 11Kv 3-□ supply from the substation is stepped down to 415V using 3-□ step down transformer. The four induction motors of different ratings and a rectifier is connected to the system as loads. Motors are used for irrigation and pumping purpose and rectifier load is used for dc applications.

The distribution line is simulated for 3sec and it is observed that the voltage and current waveforms are distorted and the power factor is reduced.

In order to improve the power factor and performance of the system DSTATCOM is connected at load end as shown in the Fig. 4

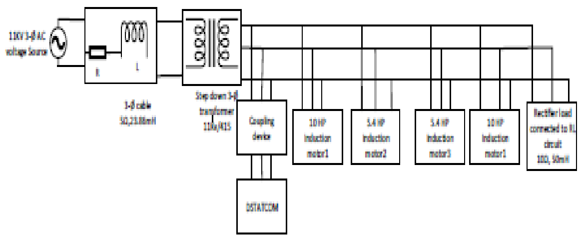


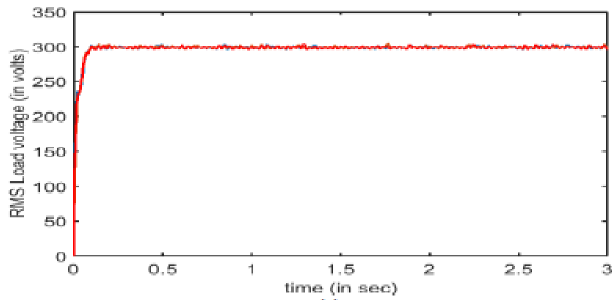
Fig. 4. Distribution line with DSTATCOM

The compensating voltage of the DSTATCOM appears across the reactors. Based on the compensator voltage and grid voltage the DSTATCOM can act either a source or sink of reactive power. As the compensating voltage is greater than the grid voltage it injects reactive power and operates in capacitive mode for improving power

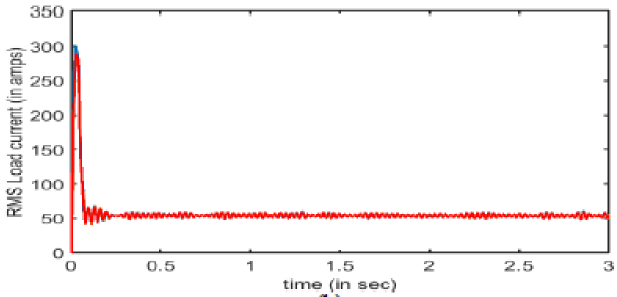
5. SIMULATION RESULTS

5.1 Wave forms without DSTATCOM

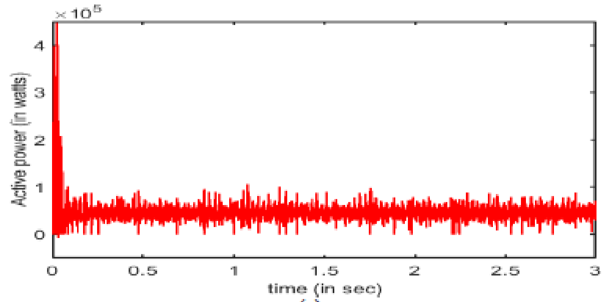
The rms load voltage, load current, active power, reactive power and power factor of the distribution line without DSTATCOM is shown in Fig. 5



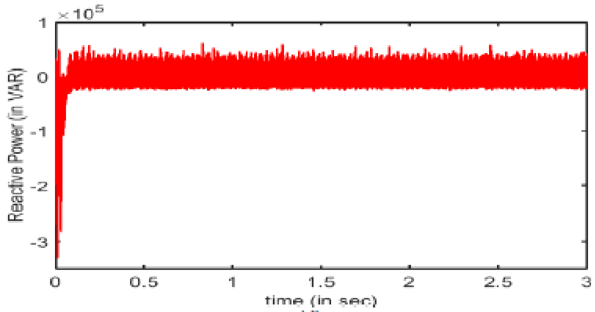
(a)



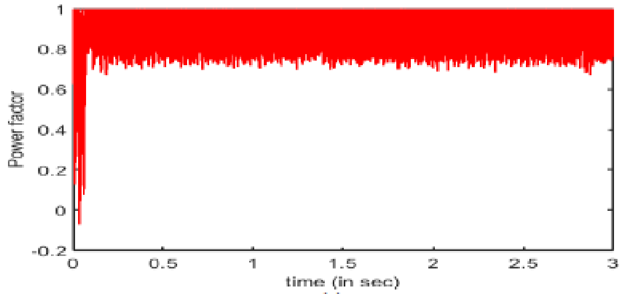
(b)



(c)



(d)



(e)

Fig. 5. Waveforms of the distribution line without D-STATCOM

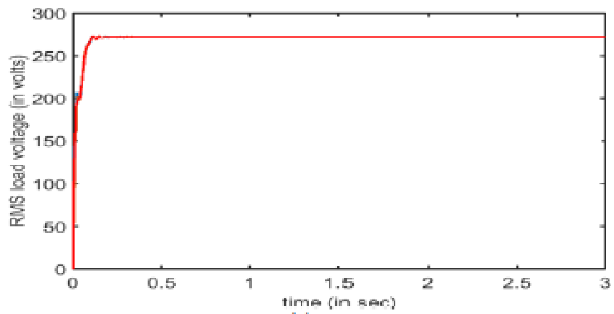
(a)RMS Load voltage (b) RMS load current
© Active Power (d) Reactive power (e) power factor

It is observed that due to induction motors and rectifier load the reactive power consumption is more which reduces the power factor. It also effects the load current and load voltage.

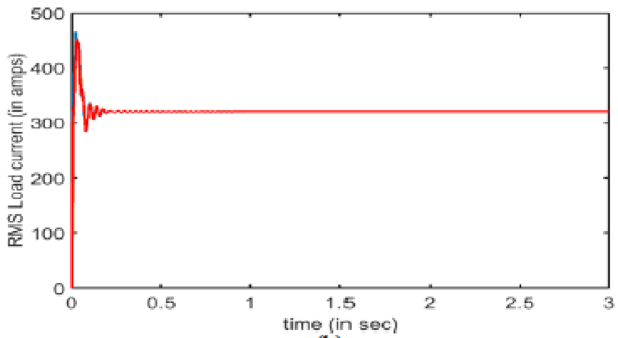
From Fig. 5 (b) it can be seen that the magnitude of the load current decreases and distorted. The power factor also reduces to 0.6 due to more consumption of reactive power.

5.2 Wave forms with DSTATCOM

The power factor of the distribution line is improved due to the shunt connection of DSTATCOM at load end. It injects the reactive power into the line to control the VAR generation. The rms load voltage, load current, active power, reactive power and power factor of the distribution line with DSTATCOM is shown in Fig. 6



(a)



(b)

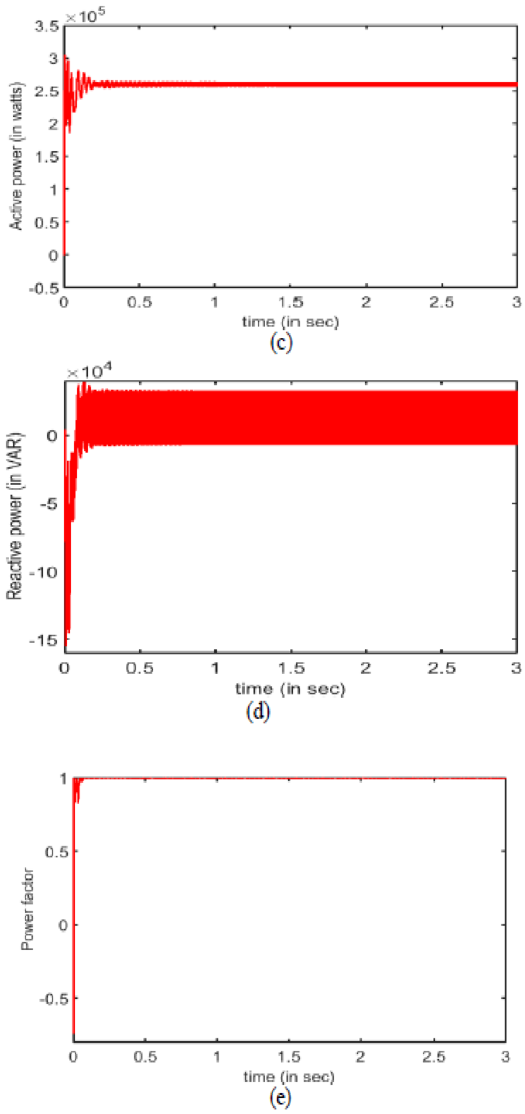


Fig. 6. Waveforms of the distribution line with D-STATCOMRMS Load voltage (b) RMS load current (c) Active Power (d) Reactive power (e) power factor

It is observed that after connecting DSTATCOM to the line the power factor increases to unity and also improved the magnitude of load current.

From Fig. 6 (a) & (b) it can be concluded that DSTATCOM also reduces the harmonics in load voltage and current in addition to power factor improvement.

From Fig. 6 (e) it can be noticed that the DSTATCOM injects reactive power into the line and works in capacitive mode for reactive power compensation.

5.3 Total Harmonic distortion (THD)analysis

a) Without DSTATCOM

Total harmonic distortion (THD) of load voltage and load current without DSTATCOM is shown in Fig. 7

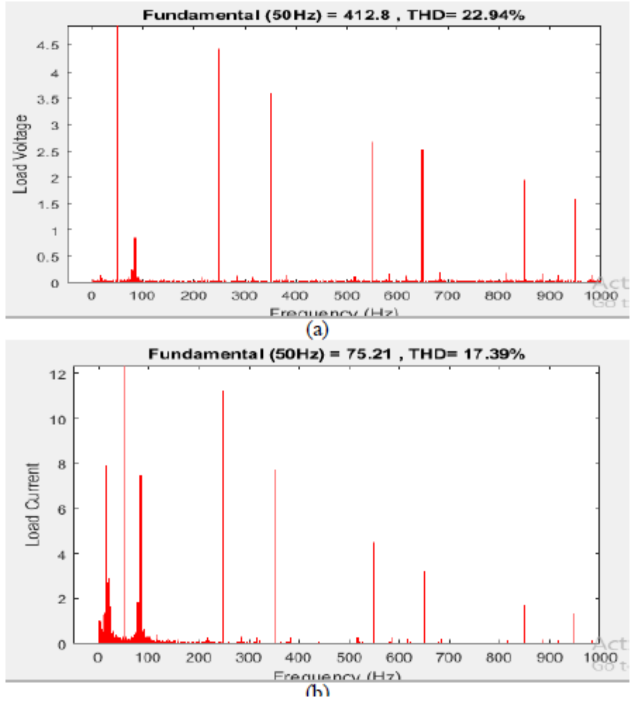
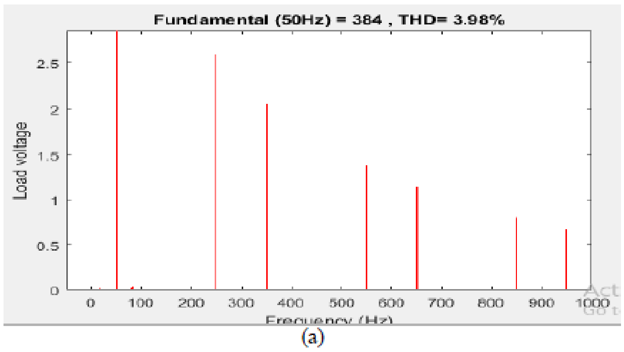


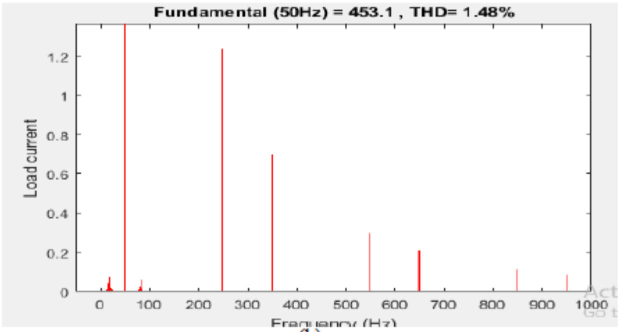
Fig. 7 THD analysis of load voltage an load current of distribution line without DSTATCOM

From Fig. 7 (a) & (b) it is observed that the THD of load voltage and load current for 50 cycles is 22.72% and 18.49%. The harmonics also effects the power factor.

b) With DSTATCOM

The DSTATCOM also reduces the harmonics in load voltage and current waveform. The Total harmonic distortion (THD) of load voltage and load current with DSTATCOM for 50 cycles is shown in Fig. 8





(b)

Fig. 8 THD analysis of load voltage and load current of distribution line with DSTATCOM

From Fig. 8 (a) & (b) it can be seen that the THD of load voltage and load current for 50 cycles are reduced to be 3.98% and 1.48%.

The THD analysis of load voltage and load current with and without DSTATCOM is tabulated in TABLE I.

TABLE I

S. NO	Feeder	THD Analysis (%)	
		Without DSTATCOM	*With DSTATCOM*
1	Load Voltage	22.94	3.98
2	Load current	17.39	1.48

SIMULATION DATA

AC supply source: 3-phase, 415V (L-L), 50Hz; line impedance: R_S =5 □, L_S = 23.86mH; Non-linear loads: 10HP and 5HP induction motors, Three phase uncontrolled rectifier load with R= 10 □, L=50mH; DC bus capacitance: 2500 micro Farads; DC bus voltage: 100V.

6. CONCLUSION

This paper presents a case study of power factor improvement on village loads. A particular zone in chandragunda village, Warangal district, Telangana is considered for demonstration. For simulation the test distribution system connected to four induction motors of different ratings and rectifier load is modeled. The power factor of the system is observed to be low due to large inductive loads. Therefore, in order to improve the power factor DSTATCOM is connected in parallel at load end. The instantaneous unit template algorithm is proposed to control the operation of DSTATCOM. It reduces the execution time and reactive power burden on DSTATCOM. The simulation results show the improvement of power factor and reduced the voltage harmonics to 3.98% and current harmonics to 1.48%. Based on the simulation results it is concluded that DSTATCOM with its proposed control algorithm improves the performance of the system.

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