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On Field Performance Analysis of Shunt Compensation of an Agricultural feeder using Power Analyzer

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Abstract

Due to misinformation and unawareness, most of the farmers do not connect capacitors to their agricultural pumps. This paper presents the on field performance analysis of shunt compensation of an agricultural feeder. Single line diagram of Low Tension (LT) distribution system, feeder measurements, location and rating of pumps are obtained by carrying out the field visit and measurements at the farmer's pump terminals. Shunt capacitors of suitable rating are connected to all the pump terminals of selected distribution transformer (DTR). Fluke 434-II power analyzer is used to record the electrical parameters before and after shunt compensation at the LT terminal of DTR. Results are analysed in detail. Energy analysis indicates that there is a huge savings in terms of energy exported after the shunt compensation. After shunt compensation there is a significant reduction in reactive power, apparent power and current supplied by DTR. Cost analysis shows that the payback period of the capacitor is in a few days.

Keywords — *agricultural feeder, power analyzer, shunt compensation, capacitor bank, reactive power compensation*

I. Introduction

India is third largest producer and consumer of electricity in the world. All India installed capacity as of March 2021 is 382.1 GW of which central sector constitutes 26%, state sector constitutes 27% and share of private sector is 47% [1]. As per the data of World Bank of year 2019; rural population in India was 65.53% of country's total population [2]. Agriculture is a crucial sector in a sustainable development of India [3]. Around 41.49% of the population generate their income from agricultural activities as of year 2020 [4]. An electric power system consists of three main stages: generation, transmission and distribution. Electricity distribution is the final stage of delivery of electricity to consumer [5]. Energy losses take place in the process of supplying electricity to load. Energy loss is defined as the difference between quantities of electricity delivered and quantities of electricity recorded as sold to customers [5]. Energy losses are due to technical and commercial losses. Technical losses are due to the energy dissipated in various power system equipments like conductor, transformer, feeder etc. Some of the causes of commercial losses are pilferage, errors in meter reading, faulty meters etc. [6]. As per Central Electricity Authority report of March 2021, the transmission and distribution loss in India were 20.66% in the year 2018-19 [1] which is considerably high as compared to other developed countries. As per studies carried out by independent agencies including The Energy Research Institute (TERI), losses in some of the states in India have been estimated to be as high as 50 precent [6].

The vicious circle of the Indian agricultural power supply is explained in [7]. Nearly all farmers in India are charged according to flat rate tariff depending on the pump HP rating; rather than actual power consumption. Also currently there are no financial incentives for farmers to improve the energy efficiency using demand side measures [8-9]. Because of this the farmers purchase unbranded,

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inefficient, low quality, and low cost pumps for irrigation. Many farmers also use higher HP rating pumps than the sanctioned one. This has resulted into the excess drawl of power from the distribution transformer (DTR) which causes low voltage at motor terminals and frequent burnout of pumps and DTR. Farmers have to spend lot of money almost every year on repairing pumps. In some cases farmers also have to spend money on repairing DTR even though DTR belongs to the utility. Utility is doing the load shedding and agricultural load is getting the power supply only for few hours in a day. In response, farmers keep their pumps ON over the night in hope that the power supply will be restored. This results into overuse of water, depletion of ground water level, scarcity of water, large voltage drop etc.

Energy efficiency is very cost-effective method of fulfilling the electricity demand. It is much cheaper to make investment in energy efficiency programs and reduce the future demand of electricity than constructing new power plants [10]. It can also play an important role in India's climate mitigation plan [11]. One unit saved at the load end is equivalent to generation of two units. Load on agricultural field is mainly due to three phase induction motors used for water pumping. Induction motors require large amount of reactive power for its operation. This reactive power needs to be supplied by the source which results in large flow of current, more voltage drop in feeder, increase in power loss, reduction in energy efficiency, increase in the loading of DTR etc. [12].

Various solutions for reducing distribution losses are described in [13]. This includes network reconfiguration [14], distributed energy resources [15], reactive power improvement [16] etc. Reactive power compensation of pump by shunt capacitors connected to each pump is a low cost solution to minimize power losses. A capacitor is an electrical circuit element that balances the phase between current and voltage and can correct the power factor in an electricity grid [17]. In this case capacitor will supply partially or fully the reactive power demanded by pump and source is relieved from supplying reactive power. A pilot project to study the effect of shunt capacitor installation at agricultural pumps on energy efficiency in distribution system is executed in rural Andhra Pradesh. Details are described in [18 - 19].

In the carried work, single line diagram of LT distribution system, feeder measurements, location and rating of pumps are obtained by carrying out the field visit and pump measurements. Based on the reactive power requirement of each pump, capacitors of suitable values are connected to individual agricultural pumps for reactive power compensation. Capacitors of 2 kVAR and 3 kVAR are connected to agricultural pump according to rating. With the help of power analyzer it is possible to automatically analyze and interpret recorded raw data into useful information with minimum human intervention [20]. Fluke 434-II power analyzer is connected at the LT terminal of DTR before and after compensation to record different electric parameters. Results are analyzed in detail. The rest of article is structured as follows: section 2 describes the system under study. Section 3 describes the calculations of shunt compensation. Results from power analyser are explained in section 4. Analysis and discussion are presented in section 5 while section 6 concludes the paper.

II. System Description

A. *Substation Description*

A 132/110/33/11kV Degaon substation,Maharashtra is situated on Solapur - Mangalwedha road. Substation is five km from Solapur city. Geographical coordinates of substation are 17°39'56"N 75°52'17"E. Both transmission and distribution stations are present in the Degaon substation.
Substation capacity is 20MVA. There are two 132kV incoming lines from Bale substation and Navi-ves substation. In substation there are total 6 transformers;

1. Two interconnected transformers (ICTs) of 132/110kV of 50MVA each.
2. Two power transformer of 132/33kV of 50 MVA each.
3. Two power transformer of 132/11kV of 25 MVA each.

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There are two 110 kV, six 33kV and two 11kV outgoing lines. Two 11 kV feeders from transmission station are given to distribution station. Distribution station is a switching station. From the distribution station there are 11 outgoing feeders of 11 kV. Out of which 11 kV Nehrunagar agriculture feeder is selected for the work as the dominant load on the feeder is due to agricultural.There are 22 distribution transformers (DTRs) of 11kV/440V on selected Nehrunagar feeder. Out of which Chandele 3 DTR (DTR code: 4094254) is selected for the work. Name Chandele 3 is given by local authority for recognition. Rating of selected DTR is 63kVA. There are total nine motors on selected DTR out of which seven are of 5 HP and two are of 7.5 HP rating.

Field visit is carried out to obtain the feeder measurements, location and rating of pumps. Single line diagram (SLD) of LT distribution system is drawn from the gathered data and shown in Fig. 1. Distances between pumps and DTR are indicated on the SLD. Based on the pump HP rating, capacitor of 2kVAR or 3kVAR is connected at the pump terminal. Detail calculation of shunt compensation is described in section III.

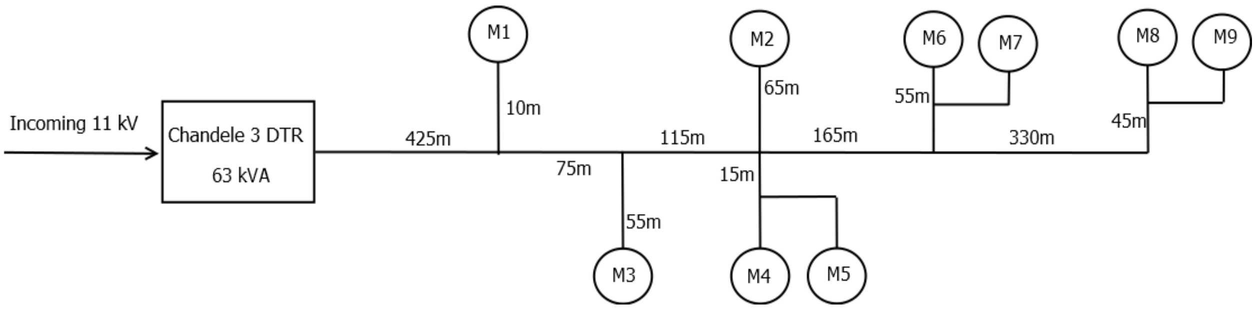

Fig. 1 Single line diagram of LT distribution system

B. *Power Analyzer Connections*

Fluke 434-II power analyzer is connected across the LT side of Chanadele-3 DTR before and after the capacitor bank installation. Instantaneous readings of various electric parameters are recorded. Fig. 2 shows the connections of power analyzer at the LT side of DTR. Electric parameters of voltage, current active Power, reactive power, apparent power, power Factor, energy and frequency are recorded by power analyzer.

Fig. 2 Power analyzer connection on the LT side of Chandele 3 DTR

III. SHUNT COMPENSATION CALCULATION

Fig. 3 shows the power triangle before and after shunt compensation.

S Q_L

S' Q_C
Q_L'

Φ_1

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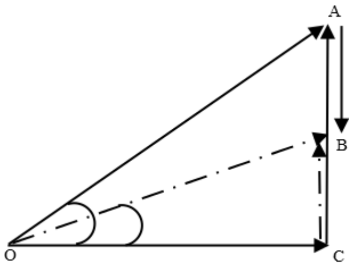

Fig. 3 Power triangle before and after shunt compensation

Meaning of various symbols is given below:

S = Apparent power taken by motor which is same as apparent power to be supplied by source

P = Active Power taken by motor, Q_L= Reactive power required for motor

Q_C = Reactive power supplied by capacitor

S' = Apparent power supplied by source after installation of capacitor

Q_L' = Reactive power supplied by source after installation of capacitor

$cos\ \phi_1$= Power factor of motor before capacitor installation,

$cos\ \phi_2$ = Desired Power factor of source after capacitor installation

f = supply frequency, C = capacitor value, Xc = capacitive reactance, Vph = phase voltage

From Fig. 3;

In ΔAOC, $tan\ tan\ \phi_1\ = \frac{Q_L}{P}$

$Q_L = P \times tan\ tan\ \phi_1$ …………………………………….. (1)

In Δ BOC, $tan\ tan\ \phi_2\ = \frac{Q_L'}{P}$

Q_L'= P $\times tan\ tan\ \phi_2$ ………………………………..…. (2)

Since, $Q_C = Q_L - Q_L$'

Putting equation (1) and (2) in above equation, we get value of Qc

$Q_C = P \times (tan\ tan\ \phi_1 - tan\ tan\ \phi_2\ )$……………………….. (3)

Also, reactive power to be supplied by capacitor is given by, $Q_C = \frac{3{V_{ph}}^2}{X_C}$

∴ Capacitive reactance Xc is given by, $X_C = \frac{3{V_{ph}}^2}{Q_C}$……………………….. (4)

Also X_c is given by, $Xc = \frac{1}{2\pi f C}$ ……………………….. (5)

From equation (4) and (5) value of capacitor that will supply reactive power of Qc is given by,

$$C = \frac{Q_c}{6\pi f V_{ph}^2} \text{……………………….. (6)}$$

Consider a case of three phase 5HP, 440V motor;

$$P = 5 \times 0.746 = 3.73kW$$

Let's assume motor power factor $cos\ cos\ \phi_1\ = 0.8\ \ \therefore \phi_1 = 36.86^0$

Desired power factor of source $cos\ \phi_2 = 0.98\ \ \therefore \phi_2 = 11.48^0$

Reactive power to be supplied by capacitor given by equation (3) is,

$Q_C = 3.73 \times (tan\ tan\ 36.86^0\ - tan\ tan\ 11.48^0\ ) = 2.03kVAR$

Capacitance that will supply about 2kVAR reactive power can be calculated from equation (6).

Practical capacitors are connected in delta. ∴Line voltage = phase voltage V_{ph} = 440V

$$C = \frac{2.03kVAR}{6\pi \times 50 \times 440^2}$$

$C = 11.12\ \mu F$……………………….. (7)

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This is the per phase capacitor value. Such three capacitors connected in delta will supply 2.03kVAR reactive power. Shunt capacitors are connected according to the HP rating of pump as given in Table I. In the carried work capacitors of 2 kVAR and 3 kVAR are connected to the agricultural pump terminals according to the pump requirement. Fig. 4 shows the photo of 2 kVAR capacitor connected to an agricultural pump terminal.

TABLE I
SELECTED CAPACITOR RATING ACCORDING TO PUMP HP RATING

Sr. no.	Pump HP rating	Capacitor rating in kVAR
1	3	1
2	5	2
3	7.5	3

Fig. 4 Capacitor connected at the pump terminal

IV. RESULTS FROM POWER ANALYSER

Readings are recorded by power analyser for 2 hours before capacitor installation and for 2 hours after capacitor installation. Time interval of data logging is set at 30 sec. Table II shows the various electrical parameters recorded by the power analyser. In the table Q, S, kW and I represent the reactive power, apparent power, active power in kW and current respectively.

Fig. 5 shows the waveform of phase voltage at the LT side of DTR before and after capacitor installation. As can be seen after shunt compensation there is significant improvement in the voltage at the transformer secondary. This is because capacitor supplies significant reactive power demanded by the pumps. Due to which the system current reduces which in turn reduces the voltage drop in the feeder resulting into improvement in the DTR voltage. Voltage gets improved by about 4%.

TABLE II
Electrical Parameters Recorded by Power Analyser Before and After Shunt Compensation

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Time	Before shunt compensation					After shunt compensation					
	Voltage (Volts)	**Power factor**	**Q/kw**	**S/kW**	**I/kW**	**Time in pm**	**Voltage**	**Power factor**	**Q/kw**	**S/kW**	**I/kW**
10:54 To 11:05	235.21	0.92	3.19	1.1	0.0016	1:44 To 1:55	241.88	0.94	0.3789	1.0659	0.0015
11:06 To 11:17	235.49	0.91	3.23	1.1	0.0016	1:56 To 2:07	240.87	0.94	0.4074	1.0758	0.0015
11:18 To 11:29	234.36	0.90	3.24	1.11	0.0016	2:08 To 2:19	239.46	0.93	0.4238	1.0817	0.0015
11:30 To 11:41	234.47	0.90	3.25	1.113	0.0016	2:20 To 2:31	239.42	0.93	0.4262	1.0849	0.0015
11:42 To 11:53	235.34	0.89	3.26	1.1153	0.0016	2:32 To 2:43	239.82	0.93	0.4328	1.0834	0.0015
11:54 To 12:05	235.84	0.89	3.27	1.119	0.0016	2:43 To 2:55	238.72	0.92	0.4308	1.0822	0.0015
12:06 To 12:17	235.46	0.89	3.27	1.11	0.0016	2:56 To 3:07	238.17	0.92	0.4262	1.0832	0.0015
12:18 To 12:29	236.53	0.89	3.28	1.1113	0.0016	3:08 To 3:19	237.39	0.92	0.4236	1.0845	0.0015
12:30 To 12:41	236.59	0.90	3.27	1.116	0.0016	3:20 To 3:27	238.4	0.93	0.4248	1.0789	0.0015
12:42 To 12:53	237.4	0.89	3.27	1.087	0.0016	3:28 To 3:35	239.43	0.93	0.4239	1.0793	0.0015

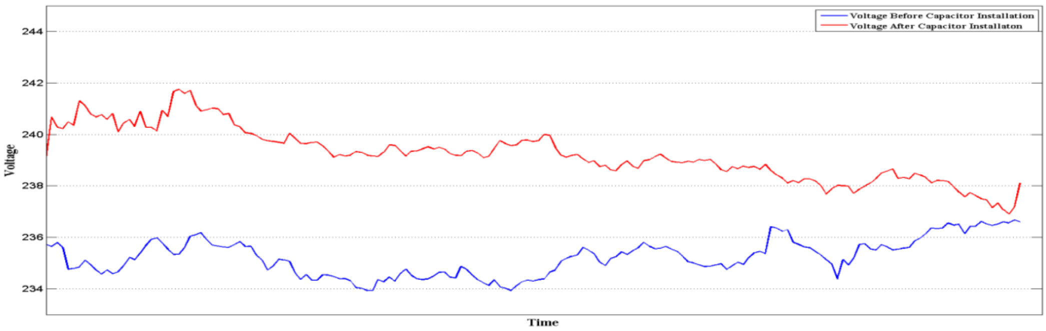

Fig. 5 Waveform of voltage before and after capacitor bank installation

Fig. 6 shows the waveform of the power factor versus time before and after capacitor installation. It can be seen that power factor is improved due to capacitor installation. Maximum power factor is reached to 0.97 after capacitor bank installation. Power factor is improved from 0.89 to 0.93 i.e. improvement of about 5%.

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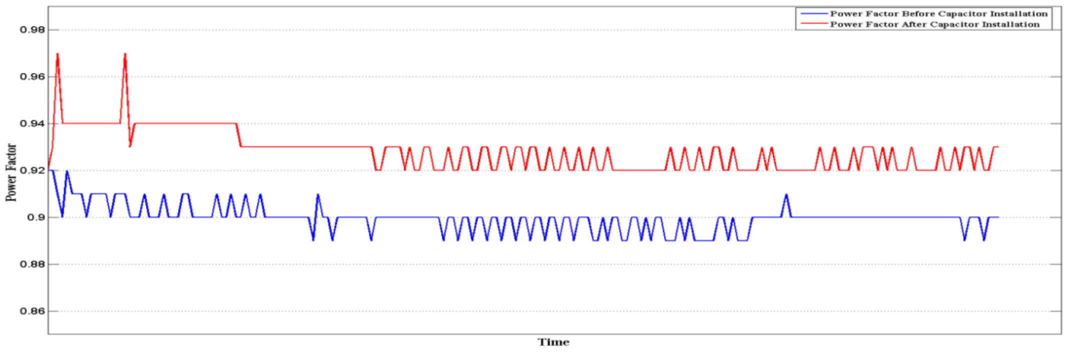

Fig. 6 Variation of power factor before and after capacitor installation

Fig. 7 shows that reactive power per kilowatt (Q/kW) and apparent power per kilowatt (S/kW) supplied by DTR. Exactly same number of agricultural pumps may not be on in both the cases i.e. before and after shunt compensation. Hence to have fair comparison; reactive power w.r.t. active power in kW and apparent power w.r.t. active power in kW is taken for the analysis. Both Q/kW and S/kW is reduced by very large amount. Reactive power and apparent power supplied by DTR get reduced by 88% and 67% respectively after shunt compensation. This is because the reactive power required by the motor is predominately supplied by capacitor connected across the individual pumps. Reduction in apparent power supplied by DTR means the transformer capacity is freed and additional load can be supplied from the existing DTR.

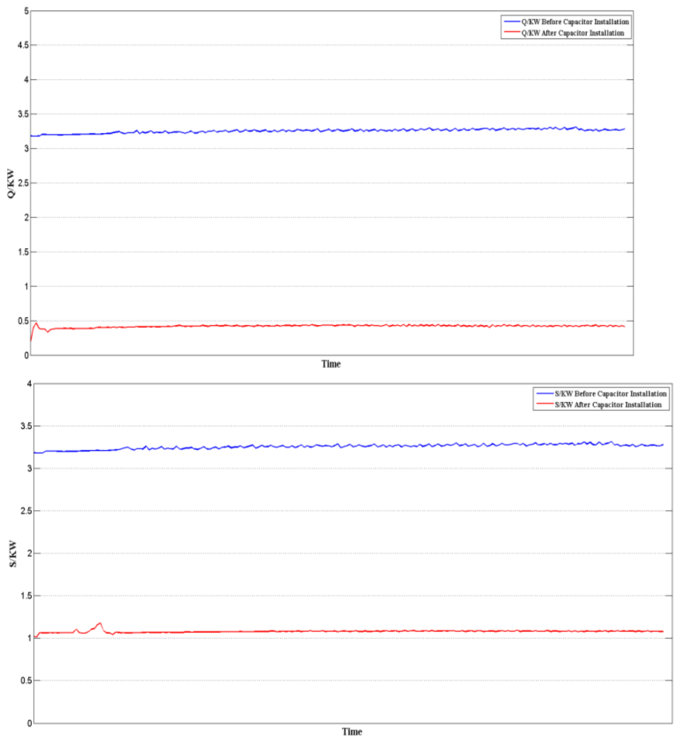

Fig. 7 Waveform of Q/kW and S/kW before and after shunt compensation

From Table II it is also clear that I/kW is reduced after shunt compensation by about 6%. As the capacitor supplies the lagging reactive component of current demanded by pump hence current supplied from DTR get reduced.

V. Analysis and Discussion

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This section describes the analysis of the results.

A. Energy Exported from DTR

From the data recorded by power analyzer

Total number of electrical units exported for a duration of 2 hours before capacitor installation = $90.707\ kWh$

Total number of electrical units exported for a duration of 2 hours after capacitor installation = $78.989\ kWh$

Reduction in electrical energy exported in 2 hours = 11.718 ≈ 12 kWh (Units)

Reduction in electrical energy exported for 1 day assuming the supply is available for 8 hours = $8 \times 6 = 48\ kWh\ (Units)$

Reduction in electrical energy exported for 1 month = $30 \times 48 = 1440\ kWh$

Reduction in electrical energy exported for 1 year = $12 \times 1440 = 17280\ kWh$

Thus by installing capacitors at the pump terminals there is very large saving in the energy supplied by utility. About 17000 units can be saved in the carried work annually. If the same scheme is adopted for all other farmer pumps of remaining DTRs then it will result into huge saving in the energy supplied by the utility. From utility point of view the saved electric units can be supplied to other revenue generating consumers like residential, commercial and industrial. Thus there is large improvement in system energy efficiency.

B. Cost Analysis

If utility or farmers themselves installs capacitor on all agricultural pumps and the electrical energy saved due to capacitor installation is exported to other revenue generating consumes. Payback period of capacitor can be calculated as follows.

Residential tariff rate is Rs. 8 per unit, hence the cost saved for a day is $48 \times 8 = 384\ Rs.$

Capacitor cost per kVAR = $125\ Rs.$

Cost of one 2kVAR capacitor $is\ 2 \times 125 = 250\ Rs.$ and Cost of one 3kVAR capacitor $is\ 3 \times 125 = 375\ Rs.$

In the carried work; total seven 2 kVAR and two 3 kVAR capacitors are connected at agricultural pumps.

Total cost of seven 2kVAR capacitors is $7 \times 250 = 1750\ Rs.$

Total cost of two 3kVAR capacitors is $2 \times 375 = 750\ Rs.$

Total cost of all 9 capacitors $= 1750 + 750 = 2500\ Rs.$

Installation cost of one capacitor = $250\ Rs.$

Total installation cost of 9 capacitors is $9 \times 250 = 2250\ Rs.$

Hence total cost including capacitor cost and installation cost= $2500 + 2250 = 4750\ Rs.$

Payback period is $4750/384 = 12\ Days$

C. Observations

- Before carrying out the research work it was observed that no farmers have installed capacitor on their pump.
- Analysis by power analyser indicates that after shunt compensation;
    i. There is improvement in voltage at DTR secondary by 4%. Due to this pumps will also get improved voltage resulting into reduction in frequent burnout of pump winding.
    ii. Current supplied by DTR get reduced by 6%. This will result into reduction in active and reactive power loss, improvement in energy efficiency and reduction in feeder voltage drop. Hence frequent burnout of DTR will be reduced requiring less maintenance to be done for DTR. Also power factor of DTR get improved by 5%.
    iii. Reactive power and apparent power supplied by DTR is decreased by 88% and 67%. Hence the loading on DTR is reduced and additional load can be supplied from same DTR.

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iv. Annual energy saving will be about 17230 units in the carried work.

v. Payback period of capacitor is only 12 days.

- This scheme can be extended to large scale and shunt capacitors can be installed on all agricultural pumps of other DTRs. It will have many benefits of reduction in energy exported from utility, voltage profile improvement, reduction in power loss, saving in the cost due to less burnout of DTR and pumps, reduction in the loading on DTR etc.

VI. Conclusions

On field Performance analysis of shunt compensation of an agricultural feeder is presented in detail. Field visit is carried out to determine the pump HP rating and the amount of reactive power compensation required by each motor. Depending on the requirement of reactive power of pumps, capacitors of 2 kVAR and 3 kVAR are connected at the pump terminals. Electrical parameters of voltage, current, active power, reactive power, apparent power, power factor and energy are recorded by Fluke 434 –II power analyzer. The data is recorded before and after shunt compensation. Results indicate that after shunt compensation; amount of energy exported by DTR is reduced by 48 units in a day, reactive power supplied by DTR is reduced by 88% and apparent power get reduced by 67%. Current supplied by DTR is reduced by 6% after shunt compensation. Voltage and power factor at the DTR terminal is improved by 4% and 5% respectively. Cost analysis indicates that the payback period of the shunt capacitor is as small as 12 days. Utility can make mandatory for the farmers to install the capacitors or utility can themselves install capacitor at individual pump to have many benefits.

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