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Research Article

Metering and Reactive Compensation Unit (MRCU) for Improved Energy Efficiency and Management - Supply of Electricity to Agricultural Consumers

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A B S T R A C T

In order to meet the growing demands of electricity, it is imperative to increase the efficiency of distribution system and reduce all wastage of energy. In this paper, the data from the distribution companies and regulatory bodies are analysed to identify the inefficiencies existing in the electricity distribution to the agriculture consumers of the state of Gujarat in India. The primary causes for the inefficiencies in the system are absence of effective monitoring and correct and reliable data on the usage of electricity by agricultural consumers, and the technical loses of electricity on account of low Power Factor and poor voltage regulation. The paper proposes a comprehensive solution to address the identified problems by way of installing a Metering Reactive Compensation Unit (MRCU) independent of consumers' energy meters. MRCU will contain capacitors for reactive compensation, relay and switching unit, metering unit for current, voltage, Kilowatt, KVARH and KWH, and LORA based communication module for 24x7 data capture. The data captured at the cloud level will be analysed by a head end software system for real time reports and corrective actions. The estimated monetary benefits from installing MRCUs for entire Gujarat's agricultural consumers is estimated to be Rs 1500 Crore in a year, apart from an estimated energy saving of close to 2000 MUs per year.

Keywords: Agriculture Distribution Network, Discom, Electricity, Energy Efficiency, Power Factor, Reactive Compensation

Introduction

To ensure that the energy demands of a growing nation are met sustainably, it is imperative to increase the efficiency of the distribution system and reduce all wastages of energy. This paper describes a proposal to increase the efficiency of electricity distribution to the agriculture consumers of the state of Gujarat in India ('Agricultural Consumers'). The distribution system and energy accounting system for all Agriculture Consumers of all four electricity distribution companies functioning in Gujarat will be analysed, based on the data and reports available in the public domain through various Tariff reports of Gujarat Electricity Regulatory Commission (GERC), websites of Power Ministries of

Government of Gujarat and Government of India, statistical reports of the distribution companies, and the audit reports of the Comptroller and Auditor General (CAG). Based on the findings of the analysis, an appropriate technology will be proposed to address the shortcomings and inefficiencies and improve the performance of distribution System, reduce the technical losses by improving Power Factor, and to encourage the consumers to participate in energy efficiency initiatives.

The Problem Analysis

The problem being addressed in this paper is multifarious. The scope of analysis and the statement of the problem are limited to the context of electricity distribution to the Agricultural Consumers of Gujarat state. The primary reason for selecting Gujarat is that its electricity sector has substantial Agricultural Consumer base, well-laid distribution network and a better Management approach. The findings and remedies proposed will not be restricted to Gujarat alone, and will be useful for other states as well.

Overview of The Agricultural Distribution System of Gujarat

There are four state-owned distribution companies (DISCOM) in Gujarat. The four DISCOMs namely, Dakshin Gujarat Vij Company Limited (DGVCL, 2020), Madhya Gujarat Vij Company Limited (MGVCL, 2020), Uttar Gujarat Vij Company Limited (UGVCL, 2020a), and Paschim Gujarat Vij Company Limited (PGVCL, 2020) cater energy to the consumers in the south, middle, north and western parts of the state, respectively. These companies are among the best performing DISCOMs in India. Gujarat's DISCOMs, under the umbrella of Gujarat Urja Vikas Nigam (GUVNL, 2020), has successfully achieved all of the targets set out by the Central Government in the Ujwal DISCOM Assurance Yojana (UDAY). At the end of FY2019-20, Gujarat DISCOMs emerged as the top-performing Indian DISCOMs with a Gross Revenue of Rs. 47,871 Crores (US$ 6650m) and net profit of Rs. 464 crore (US$65m) (GERC, 2019a).

There are over 16.75 Lakhs Agriculture Consumers, in Gujarat, catered through over 8000 dedicated Agriculture Feeders emanating from over 1600 Sub-stations of 66 kV, using 2,07,018 km 11 kV lines, about 1,33,428 km L.T. lines and 10,90,909 nos. of Distribution Transformers of capacities ranging from 5 KVA to 200 KVA (DGVCL, 2019; MGVCL, 2019; PGVCL, 2018; UGVCL, 2020b). On an average, over 19000 MUs, i.e. about 25–26 % of total electricity supplied in Gujarat, is to the Agriculture Consumers (GERC, 2019a; GERC, 2019b; GERC, 2019c; GERC 2020).

The roaster of power supply to Agriculture Consumers is normally for Eight (8) Hours a day. Apart from the three-phase supply for 8 hours, single-phase supply is also provided for the remaining 16 hours for residential uses, through the same distribution network, using special design transformers. About 29% Agriculture Consumers

Table 1.DISCOM wise Agricultural Consumers and Connected Load, FY 2019-20

Sr. No	DISCOM	No. of Consumers			Connected Load MW			MUs Sales		
		UAG	MAG	Total	UAG	MAG	Total	UAG	MAG	Total
1	DGVCL	44,184	13,8929	18,3113	183	806	989	417	461	878
2	MGVCL	26,145	15,0459	176,604	209	933	1,142	475	933	1,408
3	PGVCL	25,8457	67,6614	935,071	2,057	4,729	6,786	4,570	3,601	8,171
4	UGVCL	152,760	22,8190	380,950	2,763	2,745	5,508	6,313	3,119	9,432
Gujarat Total		**4,81,546**	**11,94,192**	**16,75,738**	**5,212**	**92,13**	**14,425**	**11,775**	**8,114**	**19,889**

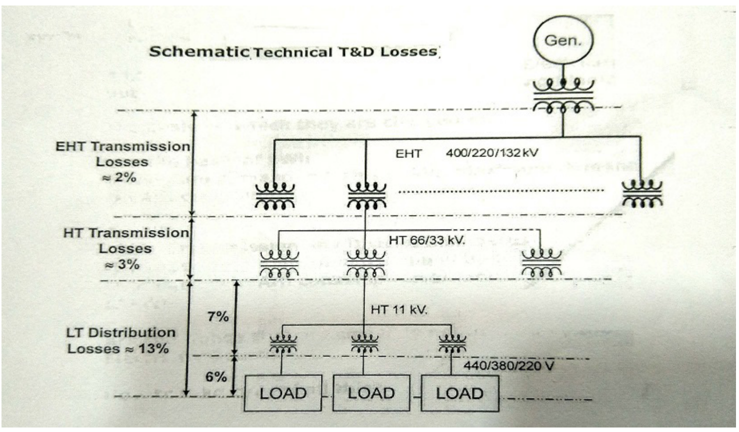

Figure 1.A General Schematic Diagram of Theoretical Transmission and Distribution Losses

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are covered under the flat Horse Power Based Tariff and 71% consumers are metered with 3 Phase Static Meters (GERC, 2019a; GERC, 2019b; GERC, 2019c; GERC 2020). The GERC tariff rate is Rs. 0.50 per unit to Rs. 0.80 per unit (GERC, 2020). There is practically no incentive for Energy conservation and as such it is estimated that 20–30 % energy catered to Agriculture Consumers is not gainfully utilised. The number of Agricultural Consumers serviced and the total connected load for all Gujarat DISCOM are tabulated in Table 1. (GERC, 2019a; GERC, 2019b; GERC, 2019c; GERC 2020).

Inefficiencies in The Distribution System for Agricultural Sector

While marked improvements have been achieved by Gujarat DISCOMs in residential and industrial segments, the agriculture distribution network has so far lagged (GUVNL, 2017). Although dedicated 11 KV Feeders for power supply to Agriculture Consumers have been created, its maintenance, monitoring and management need improvement. The capacity of the agriculture pump and motor sets varies from 3-90 HP in different areas depending upon the depth of groundwater availability and soil strata in Gujarat. Although it is mandatory to provide capacitors by the consumers on each agriculture pump load, in most cases it is not provided and, where provided, not maintained by the consumers (GERC, 2004). There is no monitoring mechanism to check the functioning of the capacitors provided by the consumers. As such the power factor of agriculture feeders is as low as 0.7-0.85 PF during the loading seasons. Low voltage conditions coupled with poor power factor, the ampere loading on Agriculture feeders are crossing the design ampere capacities. Most of the feeders are overloaded and as such the I^2R losses are high.

I^2R losses due to low power factor and flow of reactive current in the distribution network are a major contributor to the Distribution losses of utilities (Navani, Sharma & Sapra, 2012). Transmission Companies install capacitors in the transmission network to minimise losses. However, such capacitors only compensate Reactive Power towards only the source (i.e. upstream network) and not downstream;

Table 2.Share of Agricultural Consumption to Total MUs FY 2018–19 to FY 2020–21(Projected)

Sr.No	Utility	Gross MUs Sale			Agriculture MUs Sale			Share of Agriculture consumption to total MUs %		
		2018-19	2019-20	2020-21	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
1	DGVCL	19,080	19,297	20,304	840	878	916	4.4	4.5	4.5
2	MGVCL	10,004	10,446	11,076	1,318	1,408	1,498	13.2	13.5	13.5
3	PGVCL	28,610	29,668	31,859	7,712	8,171	8,630	27.0	27.5	27.1
4	UGVCL	22,400	22,968	24,584	9,240	9,432	9,614	41.3	41.1	39.1
Gujarat Total		**80,094**	**82,379**	**87,823**	**19,110**	**19,889**	**20,658**	**23.9**	**24.1**	**23.5**
% Rate of Growth			**2.9**	**6.6**		**4.1**	**3.9**		**1.2**	**-2.6**
CAGR				**4.8**			**4.1**			**-0.7**

Table 3.Category wise Agricultural Consumers and Connected load, FY 2019-20

Sr. No	Tariff Category of Agriculture Consumers	No. of Metered Consumers (MAG)	No. of Un-metered consumers (UAG)	Connected Load in MW	Rate per Unit
1	A1(HP Base Tariff)(UAG)	0	481,546	5,212	Rs.200 per HP/month
2	A2 (Meter Tariff)(MAG)	1,054,611	0	7,977	Rs.20 per HP/ month +60Paise/ KWH
3	A3 (Tatkal Tariff)(MAG)	109,074	0	814	Rs.20 per HP/month +80Paise/ KWH
4	A4 (Canal Lift Irrigation) (MAG)	189	0	6	Rs.20 per HP/ month +60Paise /KWH
5	A5 (Optional Tariff) (UAG)	30,318	0	416	50 Paise / KWH
6	**Total**	**1,194,192**	**481,546**	**14,425**	

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whereas higher amounts of losses take place in the 11 kV and LT distribution network downstream. Apart from the Transmission & Distribution (T&D) losses (Figure 1), there are also commercial losses in the system. Commercial losses are on account of theft of power and unauthorised extension of load by consumers (Antmann, 2009). Agriculture tariffs are highly subsidised, Un-metered Agricultural (UAG) consumers have a flat rate based on contracted HP. There is no monitoring system to ensure that the connected load and the contracted load are same and therefore the consumers invariably enhance the connected load without revising the contracted load, causing substantial revenue losses even under flat H.P. based tariffs.

Energy Accounting of Agricultural Consumers

Having about 16.75 lakhs Agriculture Consumers catered through about 8000 numbers of dedicated 11 kV feeders for the Agricultural Consumers, around 11 lakh Distribution Transformers, and a connected load of 14425 MW, the energy sales to the agricultural sector amounts to about 23–24% of the total energy sales in Gujarat (GERC, 2019a; GERC, 2019b; GERC, 2019c; GERC, 2020). The share of agricultural consumption in the total sale of electricity in Gujarat is stated in Table 2.

Historically, Agriculture consumption was metered since the inception of the Gujarat Electricity Board (GEB). However, in 1987, HP based flat tariff was imposed by the Government of Gujarat on GEB. Such consumers are categorised as A1 Tariff Consumers who are unmetered (UAG). A2 tariff was introduced later on and all new connections were given under this tariff which are metered consumers (MAG) and billed for metered units plus fixed charges per HP. Yet another tariff called Tatkal tariff was introduced at a higher unit rate and with a provision of getting it converted to A2 tariff on completion of five years. Such tatkal tariff consumers are categorised as A3 tariff consumers. Another tariff for pumping of water for Agriculture on the canal heads was also introduced recently with a higher unit rate and are categorised as A4 tariff. There is one more category of consumers named A5 which is an optional tariff for consumers who have opted for metered energy charges in lieu of flat HP base tariff. No new un-metered Agricultural connections are being given since 1990, the units catered to UAG are accounted as 11,775 MUs from the year 2005 and remains unchanged till date (GERC, 2019a; GERC, 2019b; GERC, 2019c; GERC, 2019d; GERC, 2020). Tariff category wise no. of consumers and their connected load in MW is tabulated in Table 3.

From Table 3, it is clear that about 28.33% of the total Agriculture Consumers are un-metered (UAG) and the connected load of such consumers is 36% of the total Agriculture connected load. Remaining 61.57 % of the Agriculture Consumers are metered consumers (MAG) having 64% of the connected load. During the year 2018-19, out of a total sale of 19,110 MUs to Agriculture Consumers, 11,775 MUs are accounted as energy sales to UAG at a normative consumption of 1700 units/HP/Annum, and balance 7,335 is considered metered energy sales for MAG. The sale of Energy to MAG consumers as reported by DISCOM to GERC is 7335 MUs and the connected load of these consumers is reported as 8704 MW i.e. 11,667,560 HP (GERC, 2019a; GERC, 2019b; GERC, 2019c; GERC, 2020). On this basis, energy billed to metered consumers works out 628.6 Kwh/HP/Annum. Both metered and un-metered consumers are catered from same AGDOM feeders, for the same hours of supply but un-metered Agriculture Consumers' consumption is taken 2.70 times higher than metered Agricultural Consumers which is a great disparity resulting into improper, inaccurate and incorrect Energy Account. While 59% of total MUs are accounted for 36% of the connected load of UAG, only 41% of total MUs are accounted for 64% connected load of MAG.

Even in the case of the MAG users, even though meter readings of all 3 phase consumers are required to be taken monthly, due to shortage of meter readers, bimonthly billing of Agriculture Consumers is resorted to. However, short cuts are often resorted to and bills issued on an ad-hoc, average, random basis. There is no cross-checking of the meter readings of the Agriculture Consumers. Some of the Agriculture Consumers are running their motors on residential feeders and bypassing the meters. The Agriculture Consumers tend to bypass the meter by directly hooking the LT lines or even transformers as there is scanty vigilance on Agriculture Consumers indulging in the theft of power. The absence of reliable consumption data, the energy accounting in respect of the agriculture sector remains inefficient.

Though it is mandatory to have meters installed even for UAGs, most UAGs refuse to allow installation of meters even if they are not billed as per the meter readings. It has been directed by Gujarat Electricity Regulatory Commission (GERC) to provide meters on Distribution Transformers catering to Agricultural Consumers, for energy accounting (GERC, 2004). DISCOMs have also reported in their compliance to GERC that all Distribution Transformers of Agriculture-Dominant (AGDOM) feeders have been provided meters. The accounting of DT meters is also done in ledger but it is difficult to believe that metering reading of these DT meters is done accurately. The very purpose of feeder wise / Distribution Transformer wise energy accounting is not served and the present system is lacking in reliability and accuracy. The situation had led to adverse mentions by the Comptroller and Auditor General (CAG) in their year 2014–15 report on public sector utilities, about the energy loss due to excess consumption of electricity by UAG consumers (CAG, 2015).

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The above analysis of the energy accounting of supply to the agricultural sector brings out the following facts:

- Normative consumption of 1700 Kwh/HP/Annum for UAG is not correct and 2.70 times higher than the average metered consumption of MAG.
- The metered consumption of 628.6 kWh/HP/Annum in the year 2019-20 is far less than the actual consumption of MAG.
- The distribution losses of 12% for the year 2019-20 are therefore far less than actual Technical and Commercial losses of AGDOM feeders of Gujarat.
- The excess consumption of 5151 MUs over actual consumption of UAG is adjusted against higher technical and commercial losses and incorrect consumption of MAG on account of irregular and inaccurate meter readings.
- There is no feeder-wise Transformer-wise energy accounting of AGDOM feeder although all AG Transformers are metered, as reported to GERC by DISCOMs.

Distribution Losses of AGDOM Feeders of Gujarat

Distribution losses are generally calculated based on energy metered on 11 kV feeder panel at the sub-station end. The energy sent out from on the feeder is the difference of the meter reading at 00:00 hrs of the starting day of the period to 24.00 hours of the last day of the period. The energy billed is the energy billed to the consumers connected on all the distribution transformers of the 11 kV feeders for the corresponding period. The difference between energy sent and energy billed is the technical and commercial distribution loss of that feeder (Seethalekshmi, Trivedi and Ramamoorty, 2002). This difference divided by the energy sent is the percentage distribution loss of that feeder. However, the Distribution losses of the AGDOM feeders of Gujarat cannot be worked out as above as there are about 29% unmetered consumers with 36% of connected load and 71% metered consumers with 64% of the connected load. The energy billed is calculated by totalling the number of consumers multiplied by their respective contracted load in

Table 4.DISCOM wise Calculation of Distribution Losses

S. No.	Particulars		DGVCL	MGVCL	PGVCL	UGVCL	GUVNL
1	Agriculture Energy Sale in MUs	UAG	417	475	4,570	6,313	11,775
2		MAG	461	933	3,601	3,119	8,114
3		**Total**	**878**	**1,408**	**8,171**	**9,432**	**19,889**
4	Connected Load in HP	UAG	245,308	280,161	2,757,373	3,703,753	6,986,595
5		MAG	1,080,429	1,250,670	6,339,142	3,679,625	12,349,866
6		**Total**	**1,325,737**	**1,530,831**	**9,096,515**	**7,383,378**	**19,336,461**
7	Per HP Sale	UAG	1,700	1,695	1,657	1,704	1,685
8		MAG	427	746	568	848	657
9		**Total**	**662**	**920**	**898**	**1,277**	**1,029**
10	Sale at average KWH per HP	UAG	162	258	2,477	4,731	7,186
11		MAG	461	933	3,601	3,119	8,114
12		**Total**	**623**	**1,191**	**6,078**	**7,850**	**15,300**
13	Sale at MAG average KWH per HP	UAG	105	209	1,566	3,139	4,590
14		MAG	461	933	3,601	3,119	8,114
15		**Total**	**566**	**1,142**	**5,167**	**6,258**	**12,704**
16	Approved Losses as per GERC	%	9.9	11.6	17	9.7	12.05
17		MUs	87	163	1,389	915	2,554
18	Energy Requirement as per GERC	MUs	**965**	**1,571**	**9,560**	**10,347**	**22,443**
19	Total Losses as per Sr. no. (3)	MUs	87	163	1,389	915	2,554
20		%	**9.02**	**10.38**	**14.53**	**8.84**	**11.38**
21	Total Losses as per Sr. no. (12)	MUs	342	380	3,482	2,497	7,143
22		%	**35.39**	**24.21**	**36.42**	**24.13**	**31.83**

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HP (GERC, 2019a; GERC, 2019b; GERC, 2019c; GERC, 2020). Such a normative calculation of losses is unrealistic and leads to incorrect assumptions as is evident from Table 4.

The losses worked out on the above basis of normative assumptions comprise of not only the technical losses but also the commercial losses due to incorrect metered consumption of MAG. It is evident from the Table 4 that the average consumption of MAG is even less than the annual average consumption of all the consumers taken together. DISCOMs have not succeeded in installing meters at the consumers' end even for realistic calculation of distribution losses due to strong objections from the consumers. As a result, the distribution losses calculated by DISCOMs considering 1700 units per HP per annum as normative consumption of UAG consumers is misleading, grossly inaccurate and allows the DISCOMs to misreport distribution losses.

Revenue from Agricultural Consumers

The revenue received from agricultural consumers is grossly inadequate. The revenue from agricultural consumers, net of subsidies given by the state government, was just Rs. 2,479 Crore as against the total revenue of Rs 47,871 Crore in the year 2019-20 (GERC, 2019a). In percentage terms, the revenue from agricultural consumers is a mere 5% as against the supply of 24% of the total billed MUs. This mismatch between supply and revenue is sought to be addressed partly through various government subsidies. Gujarat Government is bearing a large burden of about Rs. 5800 Crores for a subsidy to agriculture consumers. Rs. 1100 Crores are made in the annual budget of Gujarat government, for giving HP based subsidy to UAG. Rest of the amount is disbursed to GUVNL upon collection of the electricity duty from all other consumers by DISCOMs. Electricity duty levied by Gujarat government is meant for the development of the power sector but the almost entire amount is used to meet the obligation of subsidy. Even with the subsidy given by the State Government the revenue realisation does not cover the cost supply. As against the cost of supply @ Rs. 4.32, the agricultural revenue with a subsidy is Rs. 1.80 i.e. 42% only. This situation is, obviously, not a sustainable one (GERC, 2019a).

As discussed above, the problem with the electricity supply to agricultural consumers is multifarious. The revenue realized is not commensurate with the cost of supply. Not using the required capacitors by the consumers is affecting the efficiency of the distribution system (GERC, 2015). The high level of subsidy burden is affecting the health of government finances and the development activities of the electricity sector. There is inequity in the tariffs being charged from metered and unmetered consumers. The lack of realistic data on the energy consumed by agricultural consumers is leading to a miscalculation of technical and distribution losses and thereby affecting the efficiency of the entire system. This paper will now attempt to propose a comprehensive solution to address all these problems.

The Solution

The problem plaguing the supply of electricity to the agriculture consumers of Gujarat is complex and calls for a comprehensive solution. The solution being proposed here involves reliable and realistic capture of the data on energy consumed by the agricultural consumers, ensuring optimum efficiency of the distribution system and thereby reducing the technical and distribution losses, and involving and motivating consumers into adopting energy-saving initiatives. Various elements of the proposed solution are discussed in the following paragraphs.

Reactive Compensation for Agricultural Distribution Network

Since the electrical energy is a function of voltage, current and power factor, W= VICos Ø. The variation of power factor does impact voltage and current, given a constant load W (Nidhi & Ali, 2020). The Phasor diagram in Figure 2, shows the impact of reactive compensation.

V_L = Supply Voltage Phasor, I_L = Load Current, I_C = Capacitor Current, I_T = Compensated Current by Fix Capacitor

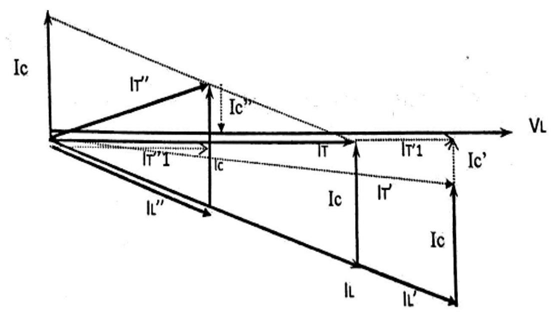

Figure 2.Phaser Diagram Showing The Impact of Reactive Compensation

Electric power has two components – active power (kWh) and reactive power (kVArh). The active and reactive power components combine to form the apparent power (kVAh). Power factor (pf) is defined as the ratio of active power to the apparent power of the system i.e. pf = kWh/kVAh ('Power Factor'). Power factor, like all ratio measurements, is a unit-less quantity. If Power Factor ratio is less than 1 it is called lagging Power Factor and is it is more than 1 then it is called leading Power Factor (Nidhi & Ali, 2020).

The active power (kWh) is consumed by the electrical equipment and converted into work for creating heat, light, motion etc. The reactive power (kVArh) is needed to provide the electromagnetic field in the inductive equipment, stored up in the windings of the equipment. Therefore while the kWh power is put to work, the kVArh power is just required to convert the electrical power into work. In the case of

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inductive loads like motors, electrical energy can't directly be converted into useful work. This is because, to convert electrical energy into rotational energy, the magnetic field has to be created in between the gaps of stator and rotor of the Motor. Hence, some amount of energy has to be used in creating a magnetic field. The portion of power that contributes to creating a magnetic field is known as 'Reactive Power' (Ansari, Mahajan & Patil, 2020).

From the efficiency point of view, Reactive Power may be seen as power loss because its role is limited to creating a magnetic field and does not contribute to driving load. Nevertheless, Reactive Power is not a loss because it creates a magnetic field without which electrical energy in stator could not have been converted to rotational energy in the rotor. Decreasing Reactive Power causes the voltage to fall while increasing Reactive Power causes the voltage to rise. Usually, power system equipment is designed to operate within a range of voltages. At low voltages, many equipment perform poorly. High voltages can damage equipment and shorten their lifetimes. Most inductive loads such as motors, transformers, ballasts and induction heating equipment require Reactive Power to produce a magnetic field. In every electrical machine, a part of input energy, i.e., Reactive Power is consumed for creating and maintaining magnetic flux to do so. However, it leads to lower Power Factor. Thus, to achieve the high Power Factor, capacitors are generally connected across these devices to supply the Reactive Power (Ansari, Mahajan & Patil, 2020).

Working with a poor Power Factor of the load leads to the higher current drawn through the supply system than the current drawn with unity Power Factor for the same kWh delivered (Ansari, Mahajan & Patil, 2020). Since copper losses are proportional to the square of the current flowing (P = I x I x R), the technical losses would increase with falling pf in the ratio of 1/(pf^2). Table 5, depicts the indicative calculations of decrease in power purchase cost due to falling pf for the year 2019-20. Presently, GERC has taken into account p.f. the ratio of 0.81 while approving the energy requirement for agriculture sales through the AGDOM feeders of Gujarat (GERC, 2020).

The electricity supply code requires that every motive power consumer should provide adequate capacitors and maintain the Power Factor (GERC, 2015). However, poor quality non-standard capacitors are installed at the time of getting the connection and once such capacitors fail, they are seldom replaced. Neither the operation of the capacitors is monitored nor checked, nor are any actions taken to enforce the discipline of maintaining Power Factor about 0.9 by Agricultural consumers. Agriculture consumers having load above 10 HP have to provide capacitors, as otherwise, their motors would not run. Here again, there is no adequacy of Reactive Compensation, no proper maintenance of capacitors, poor quality of motors, rewinding of motors etc. results into a poor Power Factor and these consumers are also required to be provided additional Reactive Power Compensation at the load end. It is therefore imperative that a basic Reactive Compensation is provided by the DISCOMs and the functioning of the capacitors monitored. These capacitors should be switched on and off with as per the dynamic Loading of the 11 kV Feeder so that an optimum Power Factor above 0.95 is maintained.

Based on the statistical data available for different connected/contracted load in HP of UAG and MAG consumers of each DISCOMs (GERC, 2019a; GERC, 2019b; GERC, 2019c; GERC, 2020), it proposed to provide 1X5 KVAR capacitor for 3 to 10 HP Agricultural consumers and

Table 5.Reduction in Power Purchase Cost due to Reactive Compensation (FY 2019-20)

Sr No	P.F	Energy Required for sale (MUs) 2019-2020		Decrease in MUs Due to P.F improvement	POWER PURCHASE IN (RS CR.) @4.32/KWH	Reduction in power purchase cost at each stage	Decrease in power purchase cost %
		Percentage of decrease in MUs	MUs				
1	0.81	1.00%	22,443	-	9,695	-	-
2	0.83	0.986	22,129	314	9,560	136	1.40
3	0.85	0.975	21,882	561	9,453	242	2.50
4	0.87	0.967	21,702	741	9,375	320	3.30
5	0.89	0.960	21,545	898	9,308	388	4.00
6	0.91	0.954	21,411	1,032	9,249	446	4.60
7	0.93	0.948	21,276	1,167	9,191	504	5.20
8	0.95	0.946	21,231	1,212	9,172	524	5.40
9	0.98	0.943	21,166	1,277	9,144	552	5.69

The overall average power purchase cost in FY19-20 of Rs. 4.32/kWh is multiplied with energy input required

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Table 6.KVAR proposed to be installed in all DISCOMs

Sr. No.	Contract HP	No. of Consumers	Connected Load in HP	Assumed Power Factor of Existing system	KVAR required to improved P.F to 0.98	Capacitor Rating per Consumer	Proposed KVAR per Consumer	Total KVAR Proposed
1	**3**	144,006	43,2019	0.7	35,4255	2.46	5	72,0031
2	**5**	589,409	294,7046	0.7	2,416,578	4.10	5	2,947,046
3	**7.5**	380,274	2,852,056	0.7	2,338,686	6.15	5	1,90,1371
4	**10**	176,060	1,760,596	0.7	1,44,3689	8.20	5	88,0298
	Sub Total	**1,289,749**	**7,991,717**	-	**6,553,208**	**5.08**	**5**	**6,448,746**
5	**12.5**	31,814	39,7680	0.75	27,0981	8.52	10	318,144
6	**15**	117,150	1,757,244	0.75	1,215,097	10.37	10	1,171,496
7	**20**	97,797	1,955,940	0.8	1,075,767	11.00	10	97,7970
8	**25**	26,299	657,486	0.8	3,616,17	13.75	10	26,2994
9	**50**	84,140	4,207,022	0.8	2,31,3862	27.50	10	84,1404
10	**75**	22,236	1,667,700	0.9	468,029	21.05	10	22,2360
11	**100**	5,264	526,400	0.9	148,041	28.12	10	5,2640
12	**125**	1,285	160,625	0.9	44,975	35.00	10	1,2850
13	**Above**	3	400	0.9	112	37.33	10	30
	Sub Total	**385,989**	**11,330,497**	-	**5,898,482**	**15.28**	**10**	**3,859,888**
	Grand Total	**1,675,738**	**19,322.213**	-	**12,451.690**	**7.43**	**6.15**	**10,308,634**

1 X 10 KVA capacitor for Agriculture consumer having load above 10 HP. Total KVAR required to be added to the L.T. Distribution Network is estimated to be 10,308 MVAR for all DISCOMs as shown in Table 6.

The Reactive Power compensation would also benefit the consumers, as for the same input energy, there will be a higher flow of water. The reduced running hours of the motors will decrease their wear and tear, saving considerable costs in repairs, replacements and maintenance. The improved quality of power supply will lead to better crop yields and more money in the hands of farmers. The subsidy provided by the government can also be linked to energy savings and routed directly to the consumers, giving them a visible and real incentive.

From the previous section, we have noticed that the accounting of energy, for about 25% of the energy supplied for agricultural purposes, in neither factual nor correct. It is based on normative consumption of 1700 HP unit per Annum for un-metred consumers. Also, there are no factual meter readings recorded for metered agricultural consumers. The T & D losses figures worked out for Agriculture feeders are also found to be far from the actuals. In the absence of the periodic and regular meter readings, it will be naive to believe that even the metered Agriculture Consumers may not tamper with the meters provided at their premises. It would therefore be necessary to deploy appropriate technology for recording the units consumed by the Agriculture Consumers independent of the meters provided at the Consumers end and to remotely collect the data of recorded units on hour to hour basis and analyse the data with a software tool for online energy accounting and audit.

Metering Reactive Compensation Unit (MRCU)

The comprehensive solution being proposed in this paper, to meet the above discussed objectives, is a Metering Reactive Compensation Unit (MRCU). The MRCU will be provided with switching relay, capacitor, contactor and long range RF communication modem. Relay will switch the capacitor contactor on or off depending on the requirement of reactive compensation to maintain a p.f. of at least 0.95. Reactive Compensation by switching on and off the capacitors at the consumer's end will enable to maintain near unity Power Factor, considerably improving the voltage profile, reduction of LT line currents and LT line losses. The functioning of the capacitor will be monitored by the communication system to be deployed, and actions can be

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taken to replace the capacitor when needed. The MRCU will also be capable of measuring current, voltage, Kilowatt, KVARH and KWH, and this data will be communicated through RS 232 or 485 ports, to the RF communication modem wirelessly connected to the web based server. A metering unit without display will be a part of the MCRU. The entire system will be Web based and capable of remote 24x7 monitoring, through the LORA communication network (Noreen, Bounceur & Clavier, 2017). Numbers 100 to 200 of LORA RF Modules may communicate with one master, with GPRS modem, which in turn will transmit the data to the cloud. The longitude and latitude of each LORA module may be mapped on Google map to ascertain and record the location of every agriculture consumer. A Head-End Software (HES) system will store and analyse the data on an hourly basis and give reports to the DISCOM. The entire MRCU will be housed in an IP 65 compliant compact box and installed at the last point in the distribution line.

Benefits of the Proposed Solution

From the analysis done on the energy accounting system based on the data of agriculture consumption of Gujarat

Table 7.Quantified Benefits of MRCU Projecteds

All amounts in Indian Rupees

Sr. No.		Year					
		2019-20			2020-21		
1	Ag. Consumers	UAG	MAG	Total	UAG	MAG	Total
2	No of Consumers	481,546	1,194,192	**1,675,738**	481,546	1,317,692	**1,799,238**
Before MRCU							
3	Energy sales in MUs	11,775	8,114	**19,889**	11,775	8,883	**20,658**
4	Energy Requirement	13,260	9,183	**22,443**	13,208	10,017	**23,225**
5	Revenue from consumers in Crore	1,664	815	**2,479**	1,664	892	**2,556**
6	Subsidy from Government in Crore	4,132	1,603	**5,735**	4,097	1,730	**5,827**
7	Total Revenue receipt in Crore	5,796	2,418	**8,214**	5,761	2,622	**8,383**
8	Per Kwh Sales Revenue in Rs.	1.41	1.00	**1.25**	1.41	1.00	**1.24**
9	Per Kwh Subsidy in Rs.	3.51	1.98	**2.88**	3.48	1.95	**2.82**
After MRCU							
10	Reduction in MUs catered by reduction in losses			**1,277**			1284
11	Reduction in commercial losses over energy catered due to Energy Account @ 3% of total energy requirement			**673**			697
12	Total reduction in MUs			**1,950**			1981
13	Improvised Energy Requirement			**20,493**			21,244
14	Estimated metered energy	6,468	11,978	**18,446**	6,353	12,832	19,185
15	Improvised Revenue receipt in Cr.	1,737.38	10,44.45	**2,781.83**	1,688.46	1,130.25	2,818.71
16	Improvised Per Kwh Revenue in Rs.	2.69	0.87	**1.51**	2.66	0.88	1.47
17	Improvised Subsidy from Government in Crore			**5,421**			
18	Improvised Per Kwh Subsidy in Rs.			**2.73**			
Quantified Benefits of MRCU							
19	Increase in Revenue in Crore	73.38	229.45	**302.83**	24.46	238.25	**262.71**
20	Reduction in purchase Cost @ 4.32 & 4.30			**842.53**			**851.7**
21	Reduction in FPPPA subsidy			**314.00**			**312.96**
22	Total Saving in Crore			**1,459.36**			**1,427.39**
23	Total Saving in US$ m			**203**			**198**

DISCOMs, it is evident that there is a huge drain of energy and revenue. Part of this drain is consumed by MAGs but does not get recorded in the meters due to poor meter reading and billing system. Part of it is also going towards theft of energy, but a sizeable portion of this un-accounted energy is the technical loss due to poor Power Factor, poor voltage regulation etc. The proposed project of regulating and monitoring supply through MRCU address all the causes of energy loss, including poor Power Factor. The correct energy accounting will enable the Government to pass on uniform Direct Benefit Transfer based on actual energy consumed by the agriculture consumers. This will provide a direct and visible incentive to the consumers, to adopt energy-saving initiatives. The main benefits of the proposed solution can be listed as follows:

- 24X7 energy accounting, auditing and vigilance support.
- Reduction in technical losses due to Reactive Compensation.
- Reduction in usage of groundwater due to quality power supply.
- Improvement in crop yields and agriculture production.
- Reduction in the energy sent out on Agriculture feeder to the extent of 10%
- Reduction in subsidy and cost of power supply.
- Reduction in Power purchase cost and generation cost.

Quantified Benefits of the Proposed Solution

The savings in the total energy consumption and the cost of supply on account of the proposed MRCU solution is as estimated in Table 7.

Conclusion

The energy accounting of Agriculture Consumers of Gujarat so far has not been accurate and correct. Even where meters are provided the reading is not regular and correct, with a limited number of meter readers and vast area of coverage. It is increasingly being difficult to correctly bill the agriculture consumers as per their actual consumption. The refusal of un-metered consumers to provide the meters even for energy accounting has compelled the DISCOMs to continue with the normative 1700 units/HP/Annum for energy accounting, which is not giving the correct picture of technical or commercial losses.

The technical losses are mostly on account of low Power Factor and poor voltage regulation. The technical loses can be reduced by providing fixed capacitor or 5KVAR or 10 KVAR for each Agriculture Consumer and monitoring remotely through the communication system as to how much Reactive Power has been injected on a minute to minute basis to enable the distribution system to maintain near unity Power Factor.

The proposal for Metering Reactive Compensation Unit (MRCU) with metering parameters monitored on 24/7 basis will meet both the purposes i.e. correct energy accounting on 24/7 basis and reduction in technical losses of energy, thereby contributing substantially to the objective of increasing efficiency of the system and reducing wastage of energy.

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