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Feasibility and Penetration of Electric Vehicles in Indian Power Grid

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Abstract**—**As the current status and growth of Indian automobile industry is remarkable, transportation sectors are the main concern in terms of energy security and climate change. Due to rising demand of fuel and its dependency on foreign countries that affects the GDP of nation, suggests that penetration of electrical vehicle will increase in near future. So in this context analysis is done if the 10 percent of conventional vehicles including cars, three wheelers and two wheelers becomes electrical vehicles in near future which is also a part of Nations Electric Mobility Mission Plan then the saving which improves the nation's economy is analyzed in detail. Whether the Indian electricity grid is capable of taking this load with current generation and demand all over the country is also analyzed in detail. Current situation of Indian grid is analyzed and how the gap between generation and demand can be reduced is discussed in terms of increasing generation capacity and energy conservation measures. Electrical energy conservation measures in Industry and especially in rural areas have been analyzed to improve performance of Indian electricity grid in context of electrical vehicle penetration in near future. Author was a part of Vishvakarma yojna in which energy losses were measured in 255 villages of Gujarat and solutions were suggested to mitigate them and corresponding reports was submitted to the authorities of Gujarat government.

Keywords**—**Vehicle penetration, feasibility, Energy conservation, future grid, Energy security, Automatic pf controller.

I. Introduction

PETROLEUM products are vital for the economic growth of the country. Out of total 157.1 MMT (Million Metric Ton) of petroleum products consumed during 2012-13 the share of diesel was the highest at 44% (69.1 MMT) while petrol accounted for 10% (15.7 MMT). LPG (Liquefied petroleum gas) and SKO (Superior kerosene oil) accounted for 9.9% and 4.8% respectively. Among the petroleum products transport sector accounts for 70% consumption all India level [1]. Indian automotive industry has its genesis in the 40's, it has observed considerable growth in the last two decades mainly due to economic liberalization including 100% FDI in the sector [2]. Global auto and component manufacturing companies are motivated to establish manufacturing and R&D facilities in the country due to availability of large pool of skilled workers, low production costs, faster design and development process and emerging market status. In the last five years there has been overall growth in automobile production (from 10.85 million vehicle in 2007-08 to 20.63 million vehicles in 2012-13).The industry contributes 7% to India's GDP, 7-8% of the total employed population (about 13 million people), 4% of exports, 39% of FDI Inflows (USD 5.5 billion between 2009-13) and contributes 17% to total indirect taxes collected [3], [4]. Indian automobile industry is the 7th largest industry in the world and will become the 3rd largest automobile industry by 2016, 2nd largest two wheeler manufacturer and the 4th largest commercial vehicle producer in world accounted for 22 per cent of the country's manufacturing gross domestic product (GDP) [5]. According to the NEMMP (Nations Electric Mobility Mission Plan) India aims to deploy 400,000 electric cars (EVs) by 2020 [5]. If this target is achieved, India can avoid importing 120 million barrels of oil and avoid 4 million tons of CO_2 emissions by 2020 based on real-world conditions of use. If these EV adoption rates continue beyond 2020 India could save 4.8 billion barrels of oil and 270 million tons of CO_2 emissions by 2030 [5].

Electric vehicle will be the important part of distributed energy resources [10]. It is also predicted as a future of Indian automobile industry but it also gives a question in mind that whether Indian power grid is ready to take up these challenges of deployment of electrical vehicles in grid and what will be the economic benefits over conventional vehicles. As focus is largely given on grid impact, range anxiety and charging speed and consideration of capacity of grid structure for electrical vehicle penetration is hardly considered [11]. Analysis is done that if 10% of total vehicles (cars, two wheelers and three wheelers) are electrical vehicles then saving of petroleum products in liters and in rupees is calculated that improves the economy of nation. Current power grid scenario has been analyzed region wise in detail which provides a view that in some of the regions in India generation is still less than the demand and shortages are found. Penetration of electric vehicles should be during off-peak periods and during peak period's vehicle should deliver to grid. Yearly load profiles are shown and from that the effective off-peak periods are identified. If India wants to become energy secure nation while generation matching the demand with penetration of electrical vehicles then energy conservation measures should be adopted. Author was a part of Vishvakarma yojna for rural electrifications where in 255 villages of Gujarat energy losses were measured and solutions were suggested to mitigate them and corresponding reports were submitted to authorities. As energy audits are not carried out at villages hence this type of analysis with energy awareness programs conducted at villages will be very useful to move India towards energy security. This paper is divided into four sections.

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1. Present scenario of total electrical vehicle in India with fuel consumption.
2. When 10% of vehicles are considered as electrical vehicle.
3. Indian power grid scenario with load pattern study for getting off-peak periods for EV penetration.
4. Energy conservation measures at villages to support demand and supply balance

For the second case following points were studied.

1. Total kWh requirement of electric vehicle (10% of total vehicle demand of India) from grid.
2. Saving of fuel with electric vehicle as compared to conventional vehicle.

With the work carried out at villages for energy conservation as case 4, below mentioned two cases are included here that shows significant saving in kWh.

(I) Energy efficient lighting.
(II) Automatic power factor controller.

Results support the penetration of electrical vehicle into grid.

II. Total Vehicles in India

As according to the society of Indian automobile manufacturer total vehicles in India are shown in Table I.

TABLE I
TOTAL REGISTERED VEHICLES IN INDIA

Total (LCVS)	Total three wheelers (passenger + goods)	Total two wheeler (scooter + motorcycle + moped)	Passenger vehicles	Commercial vehicles (passenger + goods)	Total
528297	*877711*	*15453619*	*3123528*	*38327*	*20366432*

Total vehicles in India as on 2013 are 2, 03, 66,432. India's passenger car and commercial vehicle manufacturing industry is sixth largest in the world. India's automobile exports have grown consistently and reached $4.5 billion in 2009, with United Kingdom being India's largest export market followed by Italy, Germany, Netherlands and South Africa. India's automobile exports are expected to cross $12 billion by 2014.

III. Considering 10 Percent of Vehicles Operating as Electrical Vehicles

Out of total vehicles available in country if 10% of vehicles are considered as electric vehicle than analysis is done for saving in fuel, kWh capacity required for vehicles for grid penetrating, load pattern studies for getting required off peak period for EV penetration, energy conservation required to prepare future grid for electric vehicle penetration.

A. kWh Capacity Required for Grid Penetration

Watt-hour per km capacity of vehicles is shown in Table II.

TABLE II
WATT-HOUR CAPACITY FOR ELECTRIC VEHICLES

LCVS	Two wheelers	Three wheelers
250Wh/km	37Wh/km	135Wh/km

Out of the vehicles LCVS (Light commercial vehicles), two wheelers and three wheelers, 10% of vehicle is to be converted into electric vehicles or 10% vehicles are supposed to be electric vehicles in near future then energy requirement is shown as:

LCVS energy calculations

Total LCVS available=528297
10 percent of above vehicle=52829
Wh/km for above vehicles =52829×250=13207250
=13207.250 kWh/km.
For a car travelling 40 km a day,
Daily consumption=13207.250×40=528290kWh/day.
Yearly consumption=192825850kWh/year.

Similar calculation are done for two wheelers travelling 16 km a day and three wheelers travelling 80 km a day and results of yearly consumption is shown in Table III.

TABLE III
YEARLY CONSUMPTION OF ELECTRIC VEHICLES IN UNITS (KWH)

LCVS	Two wheelers	Three wheelers	Total
192825850	*333921604*	*345993282*	*872740736*

If per unit cost of electricity is 6Rs then it will cost 5236444416 Rs.

For petrol car L/100 km= (Wh/km) ×0.01125.
For LCVS it is =250×0.01125=2.8125/100 kms

Electric vehicle with 250Wh/km will have equivalent fuel consumption of 2.814 liters/100 km assuming petrol fuel. As one car is travelling 40 km/day then in a year it will travel 14600km. For 100 km, petrol required is 2.814 liters. For 14600km, fuel requirement = 410.26 liters.

For 52829 cars yearly consumption =21673625.54 liters. Similar calculations were done on two wheelers and three wheelers and yearly consumption is shown in Table IV.

TABLE IV
YEARLY FUEL CONSUMPTION OF ELECTRICAL VEHICLE AS A CONVERSION FROM ELECTRICAL ENERGY TO FUEL ENERGY IN LITERS

LCVS	Two wheelers	Three wheelers	Total
21673625.54	*37088664*	*38924244.225*	*97686533.765*

If total consumption is multiplied by present rate of petrol which is 59Rs:

Costing in terms of Rs =5763505492 Rs.
Cost benefit of electrical vehicle operated from supply mains = 5763505492-5236444416=527061076 Rs.

B. Saving of Fuel with Electric Vehicle as Compared to Conventional Vehicle

If 10% vehicles out of the total vehicles are running on petrol and having same running period as calculated above (car runs 40 km a day, two wheelers runs 16 km a day and three wheeler runs 80 km a day) then their fuel consumption is shown in Table V.

TABLE V
YEARLY CONSUMPTION OF CONVENTIONAL VEHICLES IN LITERS

LCVS	Two wheelers	Three wheelers	Total
42850188.88	*225622706*	*85430440*	*353903334.9*

Comparing IC engine based vehicle with Electric vehicles then saving in petrol will be

= (353903334.9)-(97686533.765) =256216801.1 liters

Considering present rate of petrol 59Rs/liter than amount saved while operating vehicles on Electrical mode

$=1.5116\times10^{10}$ Rs.

As per the above result fuel consumption wise EVs have far more benefit over conventional petrol or diesel vehicles. Case study with diesel gives a similar result which shows benefits of EV for economy. A very important conclusion is derived from the number of units consumed by light vehicles, two wheelers, three wheelers and total units needed for electric vehicle, is that if only five lakh vehicles are targeted initially for electrical vehicles which is also the mobility mission plan of India than total 192825 MWh is required and at present grid installed capacity is 237742 MW. As generation projects are developing in near future but if the energy conservation measures are not taken then more electric vehicle penetration will not be possible.

IV. Indian Power Grid Scenario with Load Pattern Study

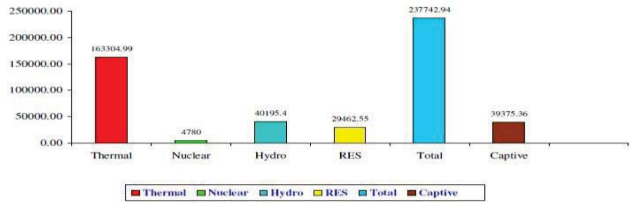

Fig. 1 Graphical representation of all India installed capacity

Fig. 1 represents that India is still largely depends on thermal power generation. Renewable energy sources are expected to rise in future [6]. Region wise installed capacity of India in MW as on 28th February 2014 is shown in Table VI [6].

TABLE VI
ALL INDIA INSTALLED CAPACITY IN MW AS ON 28-2-2014 [6]

Region	Thermal				Nuclear	Hydro	RES	Grand Total
	coal	Gas	Diesel	Total				
Northern	35283.50	5281.26	12.99	40577.75	1620	15994.75	5729.62	63922.12
Western	54069.51	9739.31	17.48	63826.30	1840	7447.50	9925.19	83038.99
Southern	26582.50	4962.78	939.32	32484.60	1320	11398.03	13127.33	58329.96
Eastern	24727.88	190	17.20	24935.08	0.00	4113.12	417.41	29465.61
North-East	60	1208.50	142.74	1411.24	0.00	1242.00	252.65	2905.89
Islands	0.00	0.00	70.02	70.02	0.00	0.00	10.35	80.37
All India	140723.39	21381.85	1199.75	163304.99	4780	40195.40	29462.55	237742.94

TABLE VII
POWER SUPPLY POSITION AND DEMAND FEBRUARY 2014

Region	Energy(MU)				Deficit (%)	
	Demand		Availability			
	Feb 13	Feb 14	Feb 13	Feb 14	Feb 13	Feb 14
Northern	19967	22396	18368	21168	-8.0	-5.5
Western	21456	23147	21046	22871	-1.9	-1.2
Southern	22544	22960	18823	21623	16.5	-5.8
Eastern	8133	8763	7756	8672	-4.6	-1.0
North Eastern	877	947	818	883	-6.7	-6.8
All India	72977	78213	66811	75217	-8.4	-3.0

Fig. 2 Load pattern in western region

Table VII shows the power supply demands existing and available from February 2013 to 2014. It can be seen that in Southern, Northern and North Eastern region considerable amount of deficit is found.

Table VIII shows the power supply peak demands existing and availability from February 2013 to 2014. It can be seen again that in Southern and North Eastern region considerable amount of deficit is found.

TABLE VIII
POWER PEAK DEMAND FEBRUARY 2014

Region	Power(MW)				Deficit (%)	
	Peak Demand		Peak Met			
	Feb 13	Feb 14	Feb 13	Feb 14	Feb 13	Feb 14
Northern	36923	37895	33494	36780	-9.3	-2.9
Western	37343	41184	36382	40331	-2.6	-2.1
Southern	35901	36427	31189	34544	-13	-5.2
Eastern	14338	14976	13585	14499	-5.3	-3.2
North Eastern	1934	2025	1845	1929	-4.6	-4.7
All India	126439	132507	116495	128083	-7.9	-3.3

Fig. 2 shows the load demand pattern of Western region [7]. It is very important to know load demand of your region, city or place so that the off-peak periods can be identified for electrical vehicle penetration. As shown in figure load in quarter April-June is mainly residential and commercial loads due to summer conditions. July-September is generally lean period due to rainy season. The quarter October-December is high demand period due to onset of Rabi season when agricultural demand is predominant with many pump sets operating. This quarter, being the festival season, commercial and residential demands are also on the higher trajectory. The quarter January-March is high demand period similar to that of previous quarter due to continuation of agricultural activities. The industrial demand is also at its peak as this is the last quarter of the financial year and target needs to be achieved before the budget. Load demand study is very important and further coordinated charging will reduce losses of distribution grid and improve the load factor [9].

V. Energy Conservation While Reducing the Gap between Demand and Supply

As seen as in 2014 deficit is less as compared to 2013 and past years. New transmission and generation projects are developing in our country but still in context of EV penetration it is needed to make up with the deficit by energy conservation. Work should be done to reduce the gap between supply and demand .In Industry people are looking after such things to an extent but in villages where a high population of India exists still there is big scope of improvement. As under Vishvakarma yojna 255 villages of Gujarat were covered where energy conservation opportunities were found in energy efficient lighting, motors, power factor improvements, solar system establishment etc. A brief case study is shown here which subsequently gives an idea that the work done for one village if can be implemented to the rest of India's villages then supply and demand gap can be reduced and system will be ready to take up the EV load in future. A case study for power factor improvement is also discussed which can be implemented to both villages and industry.

A. Case Study Energy Efficient Lighting

Primary school of village Kholvad's load is considered for case study. At this school energy conservation work was carried out. Replacement of simple tube lights was proposed with energy efficient T-5 tube lights.

TABLE IX
EFFICIENT LIGHTING CASE STUDY

conventional tube light wattage-60 watt Total Qty-48 No Usage -8 hr ./day and 250 days/year.	T-5 tube light -30 watt Total Qty-48 No Usage -8 hr ./day and 250 days/year.
Power consumption 48*60*8*250/1000= = 5760 kWh/year	Power consumption 48*30*8*250/1000= 2880 kWh/year
Net saving =5760- 2880 = 2880 units For 5 Rs./ unit charge Net saving in terms of Rs. =2880*5 = 14400 Rs. /annum Cost of T5-series tube light with fitting charge = 500 Rs. Total investment = 500*48 = 24000 Rs. The payback period = total investment/net saving per annum = 24000/14400 = 1.666 years = 20 month	

Table IX shows replacement of the simple tube light by energy efficient one. Payback period is 20 month which is quite economic. It is strongly recommended that replace conventional tube light with mechanical choke to T5-series tube light with electronics choke. Energy saving obtain from energy efficient lighting will be very useful in context of electrical vehicle penetration in Indian power grid.

TABLE X
EFFICIENT FAN CASE STUDY

Conventional fan regulator -70 watt. Total Qty -55 no. Usage -8 hr ./day and 250 days/year	Electronic fan regulator -40 watt Total Qty -55 no. Usage -8 hr ./day and 250 days/year
power consumption 55 *70*8*250/1000= 7700 kWh/year.	power consumption 55*40*8*250/1000=4400kWh/year
Net saving = 7700 – 4400 = 3300 kWh/year. For 5 Rs./ unit charge Saving= 3300*5 = 16500 RS. So the net saving in Rs /annum is 16500 Rs .Cost of electronics fan regulator with fitting charges = 110 Rs. Total investment = 55*110 = 6050 RS. Payback period = total investment/net saving per annum = 6050/16500 = 0.366 years = 5 months(approx.)	

Table X shows conventional fan regulator replaced by efficient electronic fan regulator.

1. Energy reduction can be achieved up to 61% between minimum to maximum speed by using an electronics type regulator.
2. Energy reduction can be achieved up to 32% between minimum to maximum speed by using a conventional type regulator.
3. An average of 27% reduction in energy consumption if the existing resistor type regulator is replaced with an electronics type regulator.
4. The payback period is only 5 month which is quite economic. So it is strongly recommended to replace the conventional fan regulator with electronics fan regulator.

Both the case studies show that if even a tube light and a fan is replaced in one of the school then considerable energy saving was achieved, if similar energy conservation studies apply to all major places of all villages, big potential of energy saving lies.

For LCV's type electric vehicle travelling on an average 40 km /day, with watt hour capacity of 250wh/km.

Power consumption/ year= 250×40×365 =3650kWh/year

Total energy saving per year due to energy conservation measured =6180 kWh/year.

So approximately within 20 month a car can run with the energy saving obtain from the village school by just replacing fan regulator and tube light.

B. Automatic Power Factor Controller (APFC)

Automatic power factor controllers overcome the disadvantages of individual compensation and group compensation. In Individual compensation for a particular load for example a load like motor requires three phase bank of capacitor either star connected or delta connected is installed for 80 percent the full load rating of motor. If the load of motor is changing then there can be over compensation or under compensation. Similarly for group compensation where the number of loads is connected to the bus and a single three phase capacitor bank is used to improve the power factor of the bus and the rating of the capacitor is decided on the basis of full load currents of all the motor but if at a time only few motors are running at that particular bus then it will result in overcompensation and voltage will increase. To achieve effective compensation as increase in inductive load, capacitors should be made on or off such that optimum compensation is given and kVA dependent fix charges can be reduced and it is beneficial to supply authority as well as the consumer. Power factor is improved by installing capacitor in parallel to the load. kVAR demand is reduced by PF improvement. The large number of capacitors is connected in various combination for changing the effective capacitance and kVAR, which result higher power factor. APFC are available with microprocessor and relays logic. APFC implemented for both increase and decrease in load uses principal of kVAR control [8].

kVAR control is used where voltage variation is negligible and voltage is closely regulated at a constant level. Thus voltage is not available as control variable. Capacitor are switched on or off according to system loading. As load change the capacitors are automatically switched on or off. APFC controls the power factor of the system by giving signals to switch on or off capacitors. There is power factor transducer (multi-function meter) which measures the power factor of the system and compares it with the set value and accordingly decision is taken for making capacitor banks and on off.

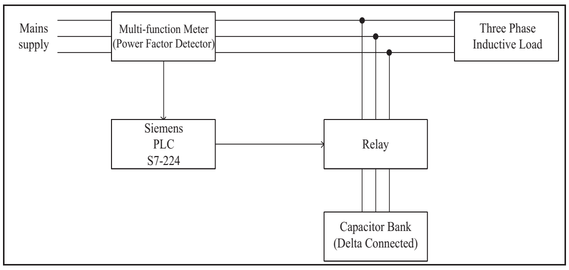

Fig. 3 Generalized block diagram of APFC using programmable logic controller

Fig. 3 shows the generalized block diagram of APFC implemented. Multifunction meter is used to read and communicate readings of voltage, current, power factor, active power, reactive power to PLC(Programmable logic control).At three phase inductive load terminals inductive load are increased and decreased and accordingly capacitor banks switching action was observed to get desired power factor.

Power diagram for automatic power factor controller is shown in Fig. 4. Three phase inductive load is connected with main bus. Main bus is protected with the help of MCB 1. For calculating power factor, multifunction meter is connected with bus. Four capacitor banks are connected in parallel with bus for drawing lagging current of inductive load. Relay's contactors are connected with capacitor banks. Further MCB 3 to MCB 6 is used for protecting capacitor banks.

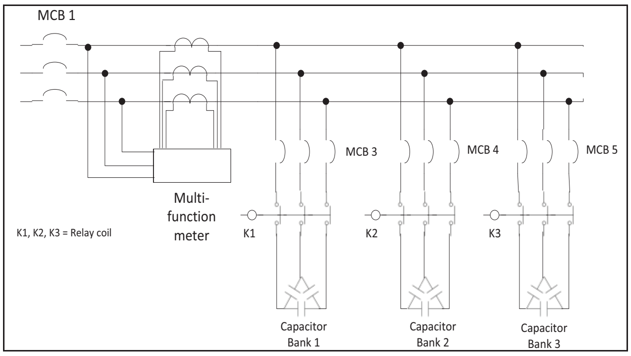

Fig. 4 Power circuit for proposed APFC

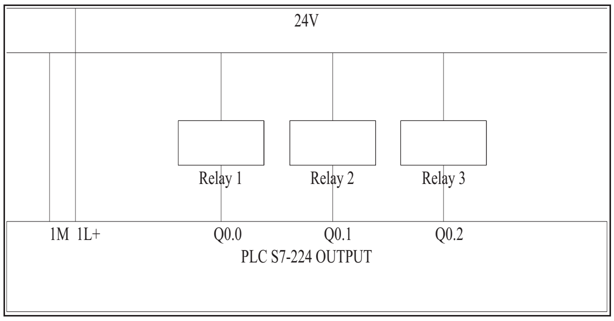

Fig. 5 Controls circuit for digital output for proposed APFC

Fig. 5 shows the digital output control circuit in which connection of three relays 1, 2, 3 to output port of PLC Q0.0, Q0.1, Q0.2 respectively.

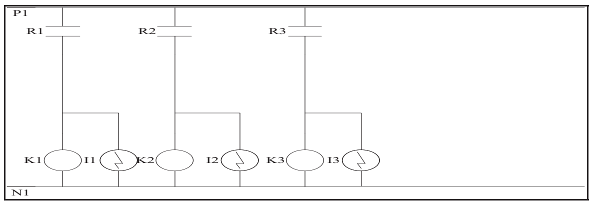

Fig. 6 Controls circuit for contactor switching for proposed APFC

Control diagram of contactor switching is shown in Fig. 6. Relay's coil and contactors are connected across auxiliary power supply of 230V, 50HZ. Indicators are connected in parallel with relay's coil.

Fig. 7 shows flowchart for proposed power factor improvement. According to the varying load reactive power changes so the value of power factor changes. In milliseconds multifunction meter will communicate this value of power factor to PLC and the required KVAR calculation is written in PLC and accordingly the capacitor bank will be on and off. As shown in Fig. 3 three phase inductive load is connected with supply, it operates at low lagging power factor. Thus capacitor banks are connected in parallel with three phase load, which draws lagging current. Concept shown here can be implemented with different rating motors and number of motors running at a time.

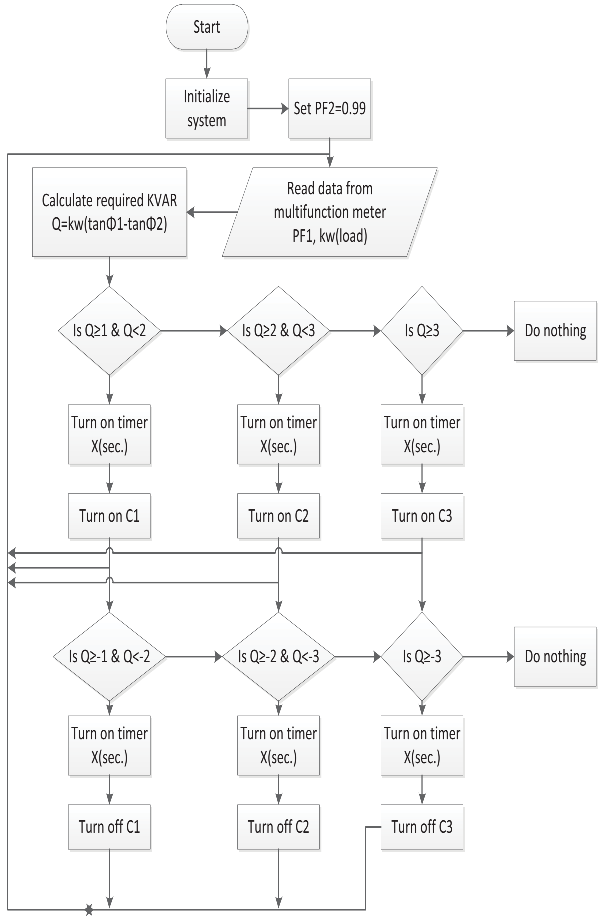

Fig. 7 Flow chart for proposed APFC

Delta connected capacitor bank is used, because for very poor power factor, it draws three time power than that of star connected capacitor bank. If load varies then we have to vary value of capacitance of capacitor bank as per load. Automatic capacitor switching can be made with the help of PLC.

Multi-function meter senses voltage and current from main bus and calculate power factor. Multi-function meter communicate with PLC with the help of RS-485 communication cable. PLC has preset value of power factor say 0.99 lagging or any value set by user.

When low power factor sensed by multi-function meter is sent to PLC. PLC compares this value of power factor with preset value i.e. 0.99 lagging and make necessary relay to operate. Relay’s contactors are closed and capacitor bank connected with this contactor operates and system draws leading current. By this way power factor improves.

$$\% \text{ Reduction in power losses} = 100\text{-}100\left(\frac{\text{orignal powerfactor}}{\text{improved power factor}}\right)2$$

Suppose original power factor=0.8
Improved power factor=0.9
Reduction in losses=21%

Energy saved by power factor improvement can be utilized in electrical vehicle penetration.

VI. Conclusion

Electric vehicle can penetrate the electricity grid with some necessary actions in the direction of energy conservation such that supply and demand gap can be reduced. Project work implemented at Gujarat’s villages shows that if energy awareness programs are conducted and energy measures are taken then considerable amount of energy can be saved, as in industries it is done through energy audit. In terms of economy also comparing gasoline engine or diesel engine with electrical operated vehicle or hybrid vehicle it shows tremendous energy saving opportunities. The load pattern of particular area should be studied to get an idea about off peak period at which EV batteries should be charged and during peak period it can supply to grid for compensating peak demands. With these precautions penetration of electric vehicles in Indian grid can be increased and that will save consider amount of crude oil and energy.

Acknowledgment

Gujarat Technological University was allotted important and prestigious project of Vishwakarma Yojana by the Government of Gujarat through Commissioner of Technical Education for the year 2012-13. The project was divided in two phase in which the first phase project has been included 85 villages & 255 villages in second phase. The first phase has been aimed to study the present status and techno-economic survey of villages in al district of the state in terms of basic and public amenities, essential commodities, other infrastructural facilities for the need of people and to prepare detail project report on adequacy of the available resource with reference to population of the village and growth of the area. It was also proposed to frame “Vishwakarma Yojana” to provide the benefit of real world experience and simultaneously apply technical knowledge in the development of rural infrastructure planning & management by students of Gujarat Technological University. A special thanks to Vice chancellor of Gujarat technological university and other officials for providing an opportunity to be a part of this fabulous program.

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