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Trilemma of Smart Distribution Grid: People, Processes and Environment

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Abstract- The paper has presented smart distribution grid from a new perspective of how the consumers ("People") and different activities ("Processes") of distribution companies are interconnected. Next, discussion has been given regarding how the core thoughts of smart grids ("Energy Conservation" and "Demand Management") are helping in reducing degradation of "Environment". These three dimensions of "People", "Processes" and "Environment" are termed as "Trilemma of Smart Distribution Grid". These three dimensions are explained in Sections 2, 3 and 4 using block diagrams and simple description of each block. Further, recommendations have been given in Section 6 for distribution companies related to their various roles (during planning and operation stages), so that the development of smart distribution can provide benefits to consumers and also take care of environment.

Keywords smart distribution grid; energy conservation; demand management; preventing environment degradation; distributed generation; planning and operation by distribution companies.

1.Introduction

Because of the advantages to consumers and distribution companies, attempts are being made in India and also in many developed and developing countries for development of smart distribution grids. There is an interesting study on establishing smart grids in Gulf Cooperation Council countries [1].

There have been many technical books and papers discussing the various features, implementations and benefits of smart grids [2-6]. When making a distribution area "Smart", there are costs involved in different "Processes" or activities; and therefore, it requires careful planning to realize the full benefits of investments. The distribution area in a large / metro city has tens of thousands of "People" or consumers and their participation all throughout is essential. The concept of smart distribution grid was started from consideration of optimizing resources with the main goal of reducing the fast "Environmental" degradation taking place in recent period.

In the present paper, it is proposed to discuss "Smart Distribution Grid" considering interactions among the three dimensions of "People", "Processes" and "Environment'. This is being called by author as "Trilemma of Smart Distribution Grid" (Fig.1).

"People" in smart distribution grid refers to consumers, which are "Domestic", "Commercial" and "Industrial" consumers within the distribution area. (In power system literature, agricultural consumers and electric traction are mentioned; but in a smart grid within a city, these are not considered.) The implementation of smart distribution grid requires involvement of people because they must come forward to balance the supply and demand of power.

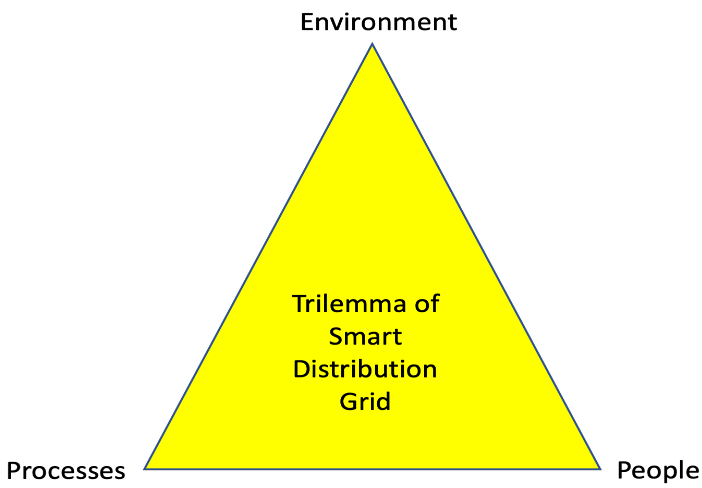

Fig.1 Trilemma of smart distribution grid

"Processes" in smart distribution grid will encompass all the activities of distribution company (DISCOM). Most of these activities are carried out with the involvement of consumers.

From the consideration of "Environment", the first idea came from the thinking that fossil fuel resources are limited and therefore, their use must be restricted. Subsequently due to "Climate Change" consideration, all the nations came forward to avoid or reduce the future use of fossil fuels. That means, no new fossil fuel-based power plants must be set up and inefficient coal-based power stations must be stopped. Instead, increased power generation must be done using "Renewable Energy Sources" (RES). Extending it to consumers, they must be persuaded not to use coal-based or diesel-based captive power in their complex. But for this, DISCOM must supply 24 x 7 quality power to all the consumers, especially to the industrial units. This concept was further extended in smart distribution grid to have energy conservations and reduction of power demand by consumers by all possible means.

Each of the three dimensions is dependent upon the other two to some extent and could also have independent areas of work. These interactions will be discussed in details in the next sections.

2. People

The main consideration in smart distribution grid is to manage the people's (consumers') power demand matching to incoming power to grid. The support from consumers is essential through various measures as shown in Fig.2.

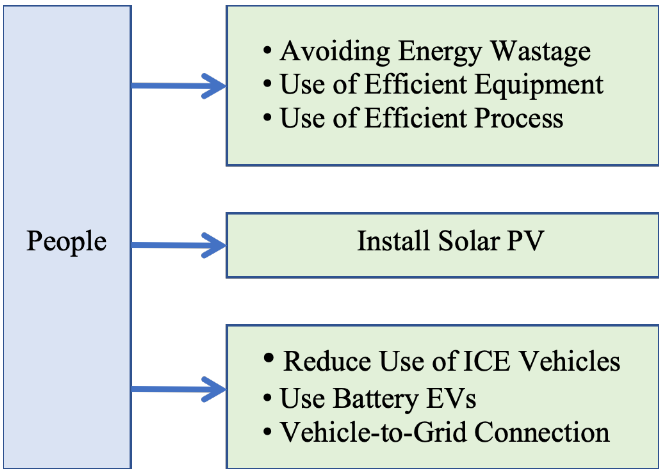

Fig.2 Involvement of people in smart distribution grid

2.1 Energy Conservation

From consideration of reducing the environment degradation, energy conservation by consumers is important activity. It can be done by: (a) avoiding wastage of energy wherever possible; and (b) use of efficient equipment and processes in houses and industries, so that for the same performance, the energy consumption is lower.

2.2 Installation of Solar Photovoltaic Power Units

Government of India (GoI) has planned to have 175 GW of power generation by RES by 2022 [7]. For this, the consumers must be persuaded to have maximum possible RES is their premises. In smart distribution grid within large / metro cities, wind energy generation may not be feasible and RES would mostly be using solar photovoltaic (PV) installations: (a) low-power solar PV unit installed on rooftops of individual houses / gated-community apartments and (b) large capacity PV plants on rooftops or in open space by government / public sector / private sector organizations.

DISCOM must educate consumers regarding the following favorable aspect of RES. (a) Cost of energy depends only on the initial investment, for which there are subsidies available from different Government schemes. (b) Once the system is installed, there is no operational cost; and they need not worry about fluctuations and ever-increasing international fuel prices. (c) The maintenance required is only periodic cleaning of PV solar panels, with very little expenditure. (d) Battery bank provided in parallel with solar PV panels can provide limited back-up power to the house.

Solar power has great potential in India with its average 300 solar days per year. Therefore, efforts are required by all concerned (authorities, DISCOM, people etc) to support this potential of energy generation to the maximum extent; which would help DISCOM in reducing power intake from coal-fired power plants and reduce emission of harmful gases by those plants.

2.3 Reduced Use of Petrol / Diesel Vehicles and Increased Use of Electric Vehicles

Use of petroleum-based vehicles must be reduced by people and correspondingly increased emphasis must be given for bringing battery-powered electric vehicles (EVs) on roads. This would be of great benefit to India due to the following reasons. (a) As the petroleum products are mostly imported, this approach would reduce the import bill of GoI. (b) With reduced tailpipe emissions, the pollution in large / metro cities would get reduced, resulting in improved environment for people to live in. (c) By having electric vehicle-to-grid connection (called as V2G), the EV would be able to feed power to distribution system during day time, which would reduce the energy bill of the consumer. But, this would also help DISCOM in meeting the peak power demand and avoid the use of costly and polluting power generators. A large fleet of EVs (as V2G) can be aggregated as "Virtual Power Plant" to support distribution system in short-term supply–demand balancing [8].

People would not go for EVs in hilly areas because of difficulties in negotiating the steep slopes by EVs and V2G implementation may not exist. In major / metro cities, where there is general awareness about climate change and protection of environment, the young citizens would like to procure the electric cars (knowing about lower running and maintenance costs, reduced noise etc).

There is a big debate on whether frequent discharging-charging of lithium-ion battery bank (for V2G) would reduce the life of batteries. The literature on battery have indicated that the life of battery is not affected by frequent charging–discharging if the battery is not discharged below about 40 per cent and then charging is done to about 90 per cent [9, 10].

Having installed maximum rooftop solar PV power (along with lithium-ion battery storage) and using V2G, consumer can have real time control and choice to generate, store and consume electricity at lowest cost available or sell it to the grid during the surplus generation (and become a "Prosumer") to reduce the monthly energy bill (through net metering). There remains a strong limit linked to consumer interests, which often cannot decide between saving and energy efficiency and above all a lack of guarantee of its desires in terms of consumption and sales. With the help of an expert and using fuzzy logic, the consumer can arrive at a practical decision [11]. A recent work gives a good information for assessment of a solar PV system for domestic household electrification [12]. Before, going for rooftop solar PV installation, the residential consumer can carry out the detailed assessment to decide the optimal rating.

3. Processes

Vision on "Smart Grids" by Government of India (GoI) is to *"Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders"* [13]. In order to attain the goals, each DISCOM must take care of its distribution zone and carry out the various "Processes" (activities) shown in Fig.3.

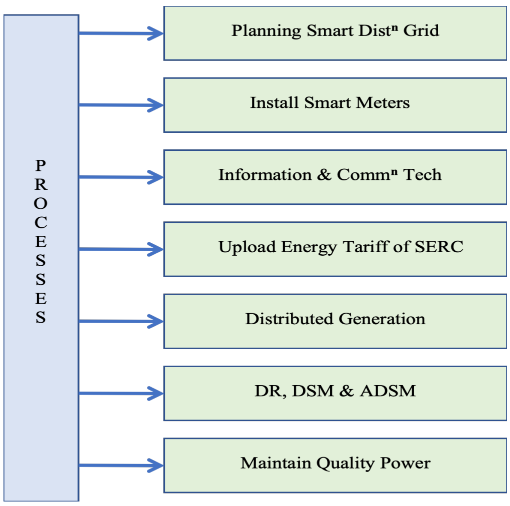

Fig.3 Processes (by DISCOM) in Smart Distribution Grid

3.1 Planning Smart Distribution Grid

At the stage of planning, DISCOM must make decision regarding layouts of underground cables or overhead distribution lines in city and locations of distribution transformers for high voltage (three-phase 33 kV or 11 kV) and low voltage (three-phase 415 V) distribution up to the premises of consumers. This is an important activity, as that would decide the power losses in distribution lines and substation transformer. With power demand increasing in every large / metro city, DISCOM must plan for the use of 33 kV underground cable for distribution in city to the maximum extent to reduce the power losses and also avoid the chance of pilferage (by hooking taking place presently on low voltage network). Thus, the complete planning activity must consider how to reduce the power losses in the grid, which would reduce power generation and help in environment preservation. The DISCOM can also decide an optimal configuration for stability and power quality improvements [14].

DISCOM must decide for gradual changing over from the existing (air-insulated) outdoor substations to indoor SF_6 "Gas-Insulated-Substation" (GIS) [15]; because GIS has many advantages over outdoor substations. The major favorable aspects of GIS are: compactness, negligible maintenance for many years, possibility of remote control, high reliability, not affected by atmospheric conditions and disturbances, etc. Therefore, DISCOM must go for indoor GIS for all new substations and also plan to change the existing old outdoor substations to GIS in the crowded places inside city. It must be mentioned that the new GIS must be housed in a separate building. But if it becomes necessary to install GIS in a multistory apartment, then it must be kept in ground floor and not in basement (to avoid flooding of GIS in case of rain water entering basement during heavy rains).

3.2 Installation of Smart Meters

Free-of-cost installation of smart meters at the panels of consumers is a major activity for DISCOM in smart distribution grid. In a large / metro city, this involves purchase of tens of thousands of smart meters and commissioning these in consumers' premises (requiring many semi-skilled workers to accomplish the job).

But, the main advantage for DISCOM in having smart meters at consumers' premises is to have "Live" information about their energy consumption at control centre through fast-digital communication to manage the grid operation. These days, DISCOMs are going for pre-paid smart meters, so that (through digital communication) consumer has information on mobile phone about his / her energy use and the balance amount, so that he / she can make advance planning for energy conservation. Consumer can top-up the amount in smart meter from mobile phone before there is automatic disconnection of power supply to the house due to negative balance amount. Thus, there would not be any manual intervention in bill preparation or collection, increasing "Collection Efficiency" and resulting in decrease in "Aggregate Technical and Commercial" (AT&C) losses for the grid.

3.3 *Providing Fast-Computing and Digital Communication System*

For making use of smart meters and for control centre to have "Live" information about all the components in the grid, it is essential for DISCOM to provide fast communication system. Making use of the "Information and Communication Technologies" (ICT), all the elements in distribution area (control centre, voltage / current / temperature sensors at all lines and equipment, smart meters, etc) will be digitally connected together. The management of such a large data at control centre would require application of "Supervisory Control and Data Acquisition" (SCADA) and "Distribution Management System" (DMS), with associated hardware and software along with trained manpower. These items and smart meters would require huge initial investment by DISCOM.

3.4 *Uploading the Revised Tariff by State Electricity Regulatory Commission*

Based on the record of past data, State Electricity Regulatory Commission (SERC) announces periodic revision of electricity tariff for different categories of consumers. The tariff also includes the "Time-of-the-Day" (TOD) structure. Then, DISCOM must upload the revised tariff in the smart meters, so that the energy bill will get prepared accordingly. It may be mentioned that the basic energy and other charges in tariff are not the same in all States.

For example for industries in hilly State of Uttarakhand, the rebate during off-peak period and penalty during peak-power period are different during winter and the other months. Also, the overall peak-power hours per day are five in case of summer and eight in case of winter. In this State, the penalty during peak-power hours is 50 per cent, which is much higher than those in all the other States [16].

In State of Maharashtra, the duration of normal charges is from 05.00 to 18.00 hrs; the peak-power demand period is from 18.00 to 23.00 hrs, with penalty charge of 20 per cent above normal during this duration, and the energy use during off-period from 23.00 to 05.00 hrs gives rebate of 25 per cent [17].

TOD tariff structures of only two Indian States are given above. In fact, many States have implemented TOD structure giving different timings of normal, off-peak and peak-power periods and penalty (during peak power period) or rebate (during off-peak period) by different percentages. The results have been quite satisfying for DISCOMs in reducing the peak power demand. Many consumers have changed the time of use of power-consuming equipment, such as, water pumping to overhead tank, use of washing machine etc to off-peak period to reduce their monthly bills. During day time, DISCOM can go through smart meter to change the temperature setting of air-conditioner and refrigerator of consumer to reduce the energy consumption, if necessary.

3.5 Distributed Generation

DISCOM must take steps to get increased additional power in the system through distributed generation. For installation of solar PV panels on rooftops, interactions of DISCOM with consumers is necessary to "hold their hand" up to the installation of these units, their getting reduction in monthly energy bills through net metering and afterwards to get regular upkeep done to get the maximum benefits of energy generation. The solar PV system would have a lithium-ion battery bank connected in parallel to it. The life of battery is lower than that of PV panels; and therefore, the consumer must be informed to get that replaced at the end of battery life.

With the development of technologies for lithium-ion batteries and their mass production in China and many other countries, the stationary battery energy storage (with battery management system) has become an essential part of distributed generation in smart distribution grid [18]. It serves many purposes. (a) It can be used to provide support to the distribution system containing variable energy sources of solar PV and wind electric units. (b) In case of power interruption, battery bank along with other distributed generation can provide back-up power for the essential services.

Another thinking fast catching up is to have large capacities of distributed generation and stationary battery energy storage units for providing most of the power demand of the smart distribution grid. This would avoid infrastructure costs in construction of new substations and new EHV transmission lines, for which getting "Right of Way" and "Environment Clearances" have become extremely difficult these days, particularly in advanced or fast-developing counties. In addition, self-managed smart distribution grid considerably reduces the transmission and distribution losses. But, management of almost autonomous system (containing large capacity variable resources) would be a challenge for DISCOM as "Aggregator".

3.6 Implementation of Demand Response, Demand-Side Management and Advanced Demand-Side Management

The main philosophy in smart distribution grid is to have demand management of consumers, so that it matches with the power received by DISCOM. For this, the different approaches are: "Demand Response" (DR), "Demand-Side Management" (DSM) or "Advanced Demand-Side Management" (ADSM) [3, 6]. This is very important activity of DISCOM to reduce or control the power demand of consumers. Considering the power losses in the equipment from power stations to loads, the power saved at loads would result in reduced generation by about three times. Thus, energy saved by consumers would result in reduced consumption of fossil fuels, decreasing the environment degradation.

Regarding control of consumers' energy consumption through DR, DSM or ADSM [19], the success for DISCOM will depend upon the cooperation by the domestic and commercial consumers. In Kerala State or Delhi or Mumbai, where the general level of education is higher, DISCOM will be able to get most of the information from the consumers and implementation of ADSM would be easy; whereas, this would be difficult in undeveloped states.

But, distribution owners must always keep in mind the ground reality that the consumers would be willing to cooperate with them provided consumers get some financial benefits or reduction in their monthly bills. For example: (a) Many consumers purchased and used LED bulbs, LED tube lights or energy-efficient fans, because GoI sold them at very low rates and these were available conveniently from many organizations. (b) With subsidies offered by Government, people are purchasing high-efficiency air-conditioners and washing machines at discount (under scheme of exchange with old equipment) being offered by the distributors. (c) TOD structure has been successful because people do not mind using some power-consuming equipment at night as there is a discount that gives reduction in their energy bill. (d) People are willing to have installation of solar PV units or agree for V2G, as they are getting reduced monthly energy bill through net metering.

3.7 Providing Quality Power to Consumers

For providing 24 x 7 quality power to consumers in complete distribution area, DISCOM must install "Distribution Static Compensators" (DSTATCOMs) at many places, so that: (a) power factor is about 0.95 at most of the locations to reduce distribution power losses; (b) there are balanced three-phase voltages with their magnitudes at nominal values; and (c) there are no voltage or current harmonics in the system which would affect the sensitive loads [20, 21, 22] etc.

In a smart distribution grid equipped with sensors (on every component of distribution system) and consumers' smart meters connected to computers in the control room, it is possible to remotely monitor and control power flow in real time on every distribution line, to every customer or even to every smart appliance inside a customer's premise (using smart meter as server or router). Therefore, in addition to the functions given by blocks in Fig.3, software can automatically perform: (a) identification of location and cause of fault when it occurs in system, and then isolation of only the faulty zone so that the other areas can continue to receive supply; (b) receive advance information in the control centre regarding overloading of any line or distribution transformer, so that steps can be taken automatically for redistribution of power flow. If this overloading happens to be a frequent occurrence, then the weak element must be strengthened. All these software and associated hardware for their successful implementation would involve huge expenditure by DISCOM. Apart from the above mentioned operation and maintenance duties, DISCOM as "Aggregator" of "Virtual Power Plant" (encompassing distributed generation, battery storage, vehicle-to-grid connection etc) must perform forecasting, advanced scheduling and dispatch of power from these new sources of energy. A recent study brings out the information related to power quality improvement using electrical vehicles (V2G) to balance the variability of solar PV output [23].

4. Environment

In developing countries (like India), the population growth is outpacing the outcome of investments made in the infrastructure and services. Further, many people are migrating to large / metro cities in search of livelihood, putting further burden on the authorities to manage the situation. The metro train and bus services are not able to cope up with the demand of people going to offices / institutions / markets. Therefore, people are going for the use of petrol or diesel-operated personnel cars or cabs, resulting in traffic jams (particularly during peak traffic hours in morning and evening) and pollution (affecting the environment and people's health). As with civil services, the situation is not satisfactory for the power distribution system.

With rapid economic growth, rising income of middle-level people in large / metro cities, and easier availability of the services or desired items (power-consuming home appliances etc), the energy demand is increasing. GoI has planned to electrify all the villages in coming few years, which would further increase the power demand. But, GoI has taken decision not to sanction new coal-based power station and getting new hydro or nuclear power stations has become extremely difficult due to many factors (mainly not able to get clearances from Environment Ministry and opposition by NGOs). Similarly, getting new EHV / HV transmission lines is becoming increasingly difficult. Therefore, authorities are forced to think of new solutions of these problems; of which smart distribution grid is one approach to manage the consumers' power demand matching to the available power.

From consideration of environment, energy conservation has become essential. GoI established a national "Bureau of Energy Efficiency" (BEE) in 2001 with the objective of improving energy efficiency in various sectors [24]. A few major activities of BEE are as follows. (a) Developing energy efficiency labels for all power-consuming appliances (such as air-conditioners, refrigerators etc), so that people will be made aware of equipment with high efficiency. Due to lower running cost, the higher initial cost gets recovered in a few years. (b) Conducting energy audits of large energy-consuming industries, so that their management will come to know the equipment / processes which are not working properly. (c) Develop benchmarks for industry energy use. (d) Develop DSM programs etc. The policies and efforts of GoI show only the direction, but people (consumers) and DISCOMs must come forward to support the steps being taken as discussed in Sections 2 and 3.

For climate change mitigation, people must be made to think of reducing their energy demand. Some of the means to achieve this goal (shown in Fig.4) can be summarized as follows.

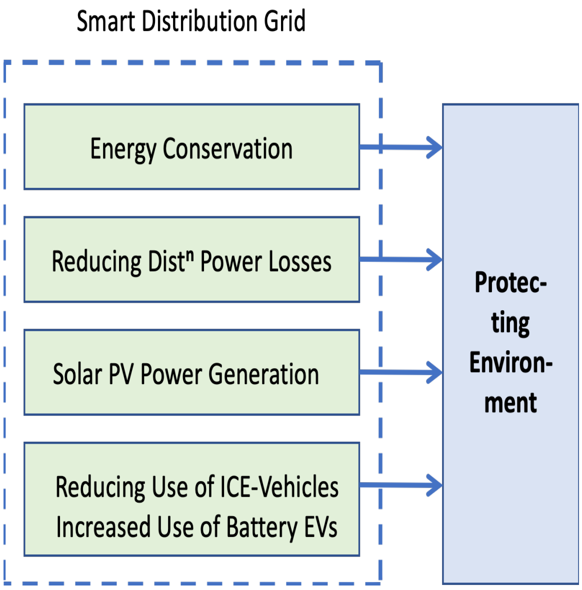

Fig.4 Different activities in smart distribution grid for protecting environment

4.1 Energy Conservation

As mentioned in Section 2.1, energy conservation must be done by "People", so that the degradation of environment can be slowed down. This is the central theme of smart distribution grid, where efforts are made by DISCOM to educate, encourage and facilitate the "People" (consumers) to come forward to reduce their power demand to match with the power being received by DISCOM. In crisis situation (during the period of peak power demand), DISCOM will send signal to consumers to reduce their demands.

4.2 Reducing Distribution Power Losses

The power losses in distribution system can be reduced by various means. (a) By proper design of distribution system, as discussed in Section 3.1, DISCOM must ensure reduced losses. (b) Increased distribution generation and energy conservation or reduced power demand by consumers (through DR, DSM or ADSM) reduces the power flow on lines and in transformers (with consumers and in substation) and thus reduces the power losses.

4.3 Increased Use of RES

Increased use of RES (as discussed in Section 2.2) must be made by consumers for power generation to reduce the dependence on use of coal for power stations. Increased renewable energy generation (in place of coal-fired power generation) has significant environmental benefits such as reduction in global warming and improved air quality by reduced greenhouse gases and carbon emissions. Another aspect not discussed openly in technical literature on smart grid is the huge quantity of ash produced from coal-fired power plant. Disposal of ash is really problematic although efforts have been made to develop products from ash. There have been several cases of the neighboring water bodies and crops getting affected during rainy seasons when the ash in storage yard starts flowing down with water in uncontrolled manner.

4.4 Increased EVs on Roads

This has already been discussed in Section 2.3.

5. Policies in India for Promotion of Smart Distribution Grid

Smart distribution grid is still at very initial stage in India. GoI has initiated a number of pilot-scale smart grid projects in a number of cities in India. Policies have been framed and are being modified based on the experiences from these pilot-scale projects. The major achievements have been guidelines or mechanisms for effective utilization of renewable energy generation in a smart grid [25]. These are given below.

5.1 Feed-in (or Fixed-Price) Tariff

It is a fixed tariff for a type of RE generation. Separate rates are fixed for the different types of RE. This has helped RE producer to get a guarantee of payment for the energy produced. This has been the major reason for the faster growth of solar PV power systems (both rooftop units and ground-mounted installations) all over India.

5.2 Accelerated Depreciation

GoI has allowed the investors of RE installations to claim 40 per cent of depreciation in the first year of operation. This helps the investors to write-off the investment quickly.

5.3 Generation-based Incentive

It provides wind energy producer certain rate per unit of electricity fed into the grid for a specified number of years.

5.4 Viability-Gap Funding (VGF)

Power generated by solar PV power is being purchased by Solar Energy Corporation of India (SECI) at a fixed levelized tariff and payment of VGF to the developer is being made at the rate mentioned in their bid.

5.5 Net Metering

It allows consumer to sell the excess energy generated by rooftop solar PV units back to grid, as recorded by meter and as per agreement made. Presently, 29 Indian States and Union Territories have released their net metering policies. Due to this, consumers are installing solar PV units without energy storage batteries, giving them reduced initial cost.

The offshoot of all the above policies has been the interest among many power organizations to establish smart distribution grids in many cities. One such success story has been the fully-established smart grid (operating since Feb 2019) in part of Delhi by Tata Power Delhi Distribution Ltd (TPDDL) to serve more than 2 million consumers; with many consumers having rooftop solar units and TPDDL's 10

MW battery energy storage [26]. In June 2019, two major power companies in India (NTPC Ltd and Power Grid Corporation of India Ltd) have formed a joint venture, called "National Electricity Distribution Company Ltd". With enough financial resources with the two organizations and with favorable government policies, many cities are expected to see the development of smart grids in the next few years.

6. Discussion

Execution and operation ("Processes") of smart distribution grid depend upon DISCOM. Therefore, a few suggestions are given below to DISCOM for their improved working.

6.1 DISCOM to Follow Guidelines and Policies of all Authorities

While executing the various activities, DISCOM must follow the guidelines and policies brought out by all Central, State and Local authorities. In India, electricity is a concurrent subject; both central government and state governments are responsible for its growth, operation and control. The central government frames overall regulations whereas each State Government or Local Body formulates the policies within the overall regulatory framework. There are different Central Ministries, each related to the concerned activity in smart distribution grid. (a) Central Electricity Regulatory Commission (CERC) is a key regulator of power sector in India, functioning with quasi-judiciary status given by Electricity Act 2003. (b) National Institution for Transforming India (NITI) Aayog is the premier policy 'Think Tank' of GoI, providing both short-term and long-term directional and policy inputs related to all the areas; (c) The Ministry of New and Renewable Energy is the nodal Ministry for all matters relating to new and renewable energy (solar PV power in smart grid); (d) The Ministry of Road Transport and Highways takes care of electric vehicles; (e) The Ministry of Power is mainly responsible for evolving general policies in the field of energy; etc. In every State, there is State Electricity Regulatory Commission (SERC) deciding the energy tariff and many other issues related to electricity sector in that State. Finally, there are Local Bodies giving the guidelines to be followed in that area, particularly related to taxes, registration etc for renewable energy implementation or electric vehicles.

DISCOM must have knowledge of policies and guidelines issued by each of the above and consider them during planning stage and when carrying out the execution of their activities discussed in Section 3.

6.2 Cooperation of "People" in Getting Benefits from Smart Distribution Grid

DISCOM is making distribution area "Smart" for realizing their main benefits of: (a) avoiding the installation of new transmission lines or substations; and (b) reducing the distribution power losses. For this, they are required to make investment in various activities related to smart distribution grid (discussed in Section 3); and must make cost-benefit analysis. DISCOM must accept that they are doing a business of "distribution of electrical energy"; and in business, "Customer (Consumer) is GOD". Therefore, they must always think of the benefits received by consumers. DISCOM must inform the consumer before starting to make the area "Smart"; and afterwards, be in constant touch with ("Hand Holding") them for solving the problems being faced.

6.3 Capacity Building (Manpower with DISCOM)

DISCOM must remember that smart distribution grid and the associated activities mentioned in Section 3 are specialized areas and require trained manpower to manage these professionally. Further, the technologies are changing fast and require periodic training programs by the authorities for DISCOM engineers or managers to keep them updated with the latest trends. The culture and traditions, educational level, geographical situation (terrain), etc are all different in the city where the smart distribution grid is being developed. Therefore, DISCOM may get the knowledge or ideas from the literatures or experiences available elsewhere, but those have to be tailored to suit the local situations. To manage hundreds of thousand consumers, hundreds of distribution lines and consumers' distribution transformers (and associated voltage / current / temperature sensors) in the grid from the control centre, powerful software supports and associated hardware (with large investments) are necessary. There must be trained engineers to operate these software programs. With DISCOM working as "Aggregator" for "Virtual Power Plant", the engineers must do forecasting, procurement and dispatch activities related to distributed generation and loads in the grid more or less on real time basis.

6.4 Training Programs for Industries

The main approach of smart distribution grid being management of consumers' power demand, DISCOM must give increased attention to energy conservation and demand control by the industries, particularly those consuming large power. For this, DISCOM must have training staff specially meant to educate the senior managers and engineers of industries. DISCOM must conduct free training programs for industries with the following objectives. (a) Informing about the latest developments in equipment and processes which would give long-term energy savings; and facilitate industries in getting loans at low interest rates for procuring these. (b) Educate them regarding installations of modern compensating equipment at their substation for improving power factor, reducing harmonic currents etc; and provide free training to electric staff in operating those equipment. (c) Make them aware about the ADSM activities of DISCOM, so that they can provide the details about the power-consuming equipment which can be controlled through smart meter by the control centre in case of crisis. (d) Inform the senior managers and engineers about climate change mitigation, reducing environment degradation etc, so that they will be willing to carry out energy conservation activities and install large capacity solar PV systems in their complex that will also reduce their energy bill.

6.5 Costs Associated with Smart Distribution Grid

When planning for smart distribution grid, DISCOM must take into account the costs associated with all their activities (discussed in Section 3). These costs are summarized below.

- Cost of project design and feasibility studies
- Costs for setting of infrastructure (distribution lines / cables, indoor GIS etc)
- Large expenditure for fast computing and digital communication system (hardware and software)
- Huge costs for purchase and installation of tens of thousands of smart meters
- Cost of project management, operation and maintenance (operating staff)
- Cost of training and development of staff
- Costs involved in conducting training programs for consumers

There are many success stories of development of smart grids abroad and in India. But, there are more examples of failures or limited success. The main reason for failures or partial success of smart grids all over the world has been that the initial part-investments were made, but the authorities could not arrange for or justify the subsequent investments to the management. Thus, smart grids developments were started but their full benefits could not be realized both for consumers and for distribution agency. In India, the development of smart grids will have limited success because of poor financial health of most of the DISCOMs.

Another point worth mentioning here is that implementation of smart distribution grid would be beneficial only in large / metro cities, because of the following reasons.

- The demand of city consumers is large and, therefore, savings through DR, DSM or ADSM would be quite substantial justifying the initial investments; that is “Benefits” to DISCOM would be commensurate with the “Costs”.
- People are knowledgeable and can be further educated about the benefits they would get by the success of smart grid through installation of smart meters, reduction of power demand through implementation of ADSM, installing solar PV system, V2G etc. When consumers realize that they are getting benefitted, they would extend full cooperation to DISCOM when required.
- Because of improved facilities in large / metro cities, many Government / Public Sector / Private organizations and institutions have their large buildings, where large capacity solar PV units can be installed on rooftops or in open space, providing enough back-up power to DISCOM.
- The citizens in large / metro cities in India are themselves facing severe air pollution, particularly during the months of November to February. Therefore, they will like to go for electric cars (having no tailpipe emissions). These electric cars (when idle) can have V2G connection to help DISCOM in peak power shaving and also give monetary benefit to consumers.

6.6 DISCOM to Strengthen Distribution System to Take Care of Increased EV Charging Loads

In the next decade, it is expected that there would be large number of EVs on Indian roads. GoI has announced plans: (a) to get 30 per cent EVs by 2030, (b) all the vehicles sold from 2030 onwards will only be electric, and (c) there must be one EV charging station in all large cities in a grid of 3kmx3km [27]. But this must be considered seriously by DISCOM as they have to strengthen the distribution network all over the cty for providing power supply to: (a) institutional buildings, apartment blocks and other parking lots for charging of personnel cars; and (b) many EV charging stations on roads in entire city. For example, the power demand in Delhi NCR for EV charging stations on city roads is given in Appendix A, and for electric bus depots in Appendix B. The point requiring attention is not the MWs or GWs calculated, but the fact that the charging of many EVs would require huge power to be supplied all over the city. Therefore DISCOMs must make their own calculations of expected power demand for different charging stations in each city and seriously start planning to change to high voltage distribution system in large / metro cities to meet the large power demands expected with rapid increase of EVs in the next one decade.

7. Conclusion

By bringing out the interconnections among the three dimensions (“People”, “Processes” and “Environment”, using the word “Trilemma”), the paper has tried to provide information to DISCOMs how their activities of planning and operation of smart distribution grid can give benefits to the consumers (people), while taking care of environment and following the guidelines and regulations of Central, State, and Local Administrations. Consumers must be persuaded or educated to go for energy conservation, installation of solar PV systems and use of electric vehicles to preserve the environment. During planning and operation of distribution system, DISCOMs must also contribute towards carbon reduction by reducing the distribution losses and installing the sources of distributed generation (such as stationary battery energy storage units).

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Appendix A

Power Demand of EV Charging Stations in Delhi NCR in 2030

- Delhi National Capital Region (NCR, having some parts of the neighboring States of Uttar Pradesh and Haryana) has an area of about 55,000 sq.km.
- As per plan of GoI, there must be one EV charging station in a grid of 3 km x 3 km (9 sq.km) in every major city. The number of EVs must be 30 per cent by 2030.
- Therefore, number of EV charging stations in Delhi NCR = 55,000 / 9 = 6,111
- It is taken that an electric car or cab has lithium-ion battery of 50 kWh and the EV comes to charging station with remaining charge of 40 per cent to get fast charging done up to 90 per cent charge in 30 min (0.5 hr). Therefore, charge required = (0.9 – 0.4) x (50 kWh) = 25 kWh.

- Power required = (25 kWh) / (0.5 hr) = 50 kW.
- It is assumed that every EV charging station has 20 charging points. Therefore, total charging power required for 20 cars' simultaneous charging in one charging station = (50 kW) x 20 = 1,000 kW = 1 MW. There would be some other loads in the charging station (for example, lighting, air compressor etc) of say 100 kW. Total power demand of one charging station = 1.1 MW.
- Total charging demand of Delhi NCR for 6,111 EV charging stations
  = (1.1 MW) x 6,111 = 6,722 MW = 6.7 GW.

Appendix B

Charging Demand of Bus Depots in Delhi NCR in 2030

- Delhi NCR has about 5,000 buses now (mostly diesel / gas–operated). It is assumed that by 2030, there would be a total of about 10,000 buses. With a fleet of 30 per cent electric buses (e-buses), the number of e-buses = 3,000 assumed to be located in 30 e-bus depots; that is 100 e-buses per depot.
- It is assumed that each e-bus has lithium-ion battery bank of 300 kWh and comes to depot with remaining 40 per cent charge for fast charging up to 90 per cent charge in 30 min (0.5 hr). Therefore, charging required
  = (0.9 – 0.4) x (300 kWh) = 150 kWh.
  Charging power = (150 kWh) / (0.5 hr) = 300 kW.
- If it is assumed that, out of 100 e-buses of one depot, 20 per cent of e-buses come back to depot after one trip for simultaneous charging during day time, then power demand in one e-bus depot
  = (0.2 x 100) x (300 kW) = 6,000 kW = 6 MW. There would be some other loads in the charging station (for example, lighting, air compressor etc) of say 100 kW. Total power demand of one charging station = 6.1 MW.
- Power demand for 30 e-bus depots in Delhi NCR
  = 30 x (6.1 MW) = 183 MW.