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Multi-Agent System Based Two-Phase Market Model to Incorporate Demand Response in Grid-Tied Microgrids

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Abstract- In this paper, a MEMF is proposed to manage power balance in grid-tied microgrids. The MEMF maintains two virtual markets viz. Local market in which potential sellers and buyers will participate in trading within the microgrid using CDA market auction, and Global market in which power mismatch (surplus/deficit) of the microgrid in the local market is mitigated by the grid. In addition, a novel linear bidding algorithm is introduced for stake holders to decide their quote prices for day-ahead trading intervals for ethical trading. The trading mechanism is modified dynamically to enhance benefits to both sellers and buyers. It also enables customers with low priority loads to participate voluntarily in DR. The generally used incentive policy is modified to yield more benefits to the customers. In the proposed MEMF, both MAS and grid-tied microgrid are simulated using MATLAB/SIMULINK. The simulation results on a test system are presented for illustrating the effectiveness of DR on the proposed trading and managing algorithm.

Keywords: Microgrid, Demand Side Management, Demand response, Multi-Agent System, and Continuous Double Action Protocol.

NOMENCLATURE

MEMF	Multi-Agent Based Intelligent Energy Management Framework
CDA	Continuous Double Action
DR	Demand Response
MAS	Multi-Agent System
DG	Distribution Generation
DERs	Distributed Energy Resources
DSM	Demand Side Management
DN	Distribution Network
LDC	Load Distribution Centre
AP_{DGx}	Ask prices of potential sellers
AP_{DG1}	Ask price of DG1
AP_{DG2}	Ask price of DG2
BP_{LDCx}	Bid prices of potential buyers
BP_{LDC1}	Bid price of LDC1
BP_{LDC2}	Bid price of LDC2
GBP	Grid Buying Price
GSP	Grid Selling Price
WALP	Weighted average of limiting prices of grid (GSP and GBP)
MCP_{Sx}	Market clearing price of stake holder using CDA protocol
MCP_{DGx}	Market clearing price of DGx using CDA protocol
MCP_{LDCx}	Market clearing price of LDCx using CDA protocol
LCP	Load clearing prices
ΔP_{LDCx}	Supply demand mismatch in LDCx after local market auction
MCGSP	Market cleared grid selling price
MCGBP	Market cleared grid buying price
$MCMGP_{LDCx}$	Market cleared DGx power to LDCx from local market using CDA protocol.
$LDCx_{TL}$	Load demand of LDCx.
GP_{DGx}	Day-ahead real-time generation of DGx
C_{DGx}	Rated capacity of DGx
MD_{LDCx}	Maximum demand of LDCx
UGA	Utility Grid Agent
MIAA	Microgrid Intelligent Aggregator Agent
DGAx	Distribution Generation Agents
LDCAx	Load Distribution Centre Agent
LAxy	Load Agents
P_{MG}	Consolidated power availability in microgrid

TL_{MG}	Consolidated load demand of microgrid
$GLSP_{DGx}$	DGx selling power in global market
$GLBP_{LDCx}$	LDCx buying power from global market
$MGSP_{UG}$	Microgrid selling power to grid in kW
$MGBP_{UG}$	Microgrid buying power from grid in kW
SP_{MG}	Microgrid Selling price/kWh
BP_{MG}	Microgrid Buying price/kWh
$MCSP_{DGx}$	Total market cleared DGx selling price/kWh
$MCBP_{LDCx}$	Total market cleared LDCx buying price/kWh
$MIAP_{TI}$	MIA profit price / time interval
L_{XY}	Load connected in LDCx
TL_{Lxy}	Total Load consumption of L_{XY}
DLCF	Distributed load consumption factor
C_{CLP}	Clearing power of the customer
GP_{AP}	Give-up power

1. Introduction

Integration of DERs into the traditional DN for economic, environmental and security benefits, constitutes a microgrid which can operate either in grid connected [1,2] or islanded mode [3,4]. The large penetrations of these sources and the implementation of smart distribution technologies such as smart metering/smart appliances have changed the DN from passive to active systems [5,6]. The optimal scheduling [7] and monitoring [8] along with the necessary protection systems [9, 10, 11] are the related challenges.

The DSM [12] techniques, particularly employing DR [13], can effectively ease the security constraints in a more economical way. For this, DNs will have to accommodate bi-directional power flows employing suitable trading mechanism. Incorporation of these facilities in to the network will make the DN more complex, with changing configuration and behaviour. An effective energy trading and management system for the current competitive energy market is therefore required.

The deployment of energy trading and management system in smart DNs need a distributed intelligent framework in terms of agents [14,15]. Agents are individual entities that react to changes in the environment, schedules auctions and are able to interact with other coexisting agents [16]. A system developed with a group of such loosely coupled agents is called MAS [17]. MAS are physically and/or logically dispersed, and posses self-governing behaviour. They are linked together through interaction and cooperation to complete a complex task. MAS can co-ordinate in: (i) centralized [18,19], (ii) decentralized[3,20], and (iii) a combination of both [21,22] control strategies.

Integration of large number of local generation and distribution companies into the power system has made electricity markets to be organized as pools [23]. Generation and distribution companies are most concerned about building an optimal bidding strategy in order to maximize profits in the present competitive electricity market [24]. In [14,25,26] H.S.V.S. Kumar Nunna et.al., have presented a zero-intelligence-plus bidding algorithm for the stake holders to decide their quote prices for market auction, and a MAS based energy trade mechanism using CDA protocol between potential sellers and buyers (stake holders) in a grid-tied microgrids. But the global market prices are fixed. In [27], Kaixuan Chen et.al., have presented a prediction-integration strategy optimization model for prosumers in the CDA-based electricity market to allow the bidding auctions and prosumer operations based on Extreme Learning Machine. In [28], Jian Wang et.al., have reported a direct electricity transaction mode between DG (seller) and consumer (buyer) in a microgrid, based on the combination of blockchain and CDA mechanisms. In [29], Y. Zhou et.al., have presented an optimal algorithm to generate the residential appliances working time table for minimizing electricity bill based on the constraints with the appliances, personal life habit and power limitations.

This article proposes a decentralized MEMF as an effective energy management system incorporating a new linear bidding algorithm for stake holders in the local market and a novel energy trading mechanism producing varying market clearing prices in the global market based on the supply-demand mismatch of the microgrid. The proposed energy trade mechanism will enable the microgrid to conduct market auctions for potential sellers and buyers to achieve benefits for all the stake holders.

The smart DN considered in present work is a grid-tied microgrid. The prototype consists of two DG units, two LDC (representing retailers) connected with smart homes (representing customers), and this combination is connected to the main grid. The proposed MEMF maintains two phases of markets viz. Local and Global markets. Local market facilitates internal trading within the microgrid using CDA protocol [14,30,31,32]. Whereas global market facilitates two types of trading mechanisms between microgrid and main grid. A novel linear bidding algorithm is introduced to decide quote prices of stake holders in real-time for market auction to conduct ethical trading between the stake holders. Besides assisting trading, MEMF encourage/allow customers to participate in DR program voluntarily. It provides a platform for customers to relinquish a part of their allotted power from local resources to receive the available incentives. This relinquished power will act as a virtual generator.

The MEMF allows: (i) energy buyers and sellers to decide their day-ahead quote prices (selling/ask and buying prices) using proposed linear bidding algorithm, (ii) organizes a day-ahead action according to CDA algorithm and allows energy buyers and sellers to trade with each other in local market, and (iii) power imbalance (surplus/deficit) in local market will be transferred to global market, wherein the difference power is traded using a new mechanism.

The rest of the paper is organized as follows: Section 2 presents a new two-phase energy trade mechanism. Section 3 describes a linear bidding algorithm to decide quote prices of stakeholders for day-ahead trade intervals. The multi-agent based architecture to incorporate DSM and the roles of various agents involved are discussed in Section 4. Section 5 reports the simulation results of a case study with 6 demand intervals for a grid-tied microgrid system. Finally conclusions are drawn in Section 6.

2. Energy Trade Mechanism

In this work, two phases of market auctions i.e. Local and Global markets are modeled to clear the market trading. All possibilities are considered to achieve power balance in the local market using the available resources. If there exist is a difference power in the local market, the global market is used to balance supply and demand. To address the market operations, an aggregator concept is used [33,34,22]. An aggregator is an intelligent agent which collects the data pertaining to: (i) power availability from DG units in the microgrid, (ii) load demand of the LDC, and (iii) import/export power from/to grid to maintain the power balance in the microgrid. Aggregator is also responsible for collecting real-time day-ahead quote prices of stake holders through their respective agents to match potential seller and potential buyers, and to calculate the market clearing price at which power will be traded in the power market.

2.1. Local Market

For local market auction, aggregator uses CDA trading protocol to clear the market. In the CDA, potential buyers submit their bids to purchase a unit of goods and potential sellers simultaneously submit their ask prices to sell a unit of goods to an auctioneer. Where lowest ask price is called the outstanding ask (oa) and highest bid is termed as the outstanding bid (ob) in the market [35]. The auctioneer declares the clearance price of the market, where the clearing price is the weighted average of the lowest ask and the highest bid, thus providing 50% benefit weightage to both seller and buyer. For each trader in CDA market, there is an acceptable price range [PL and PU].PL is the lowest acceptable price and PU is the highest acceptable price in the market. In this work, GBP and GSP are the corresponding limiting prices of the market.

In the proposed MEMF, two DGs are considered as potential sellers and two LDCs are considered as potential buyers for CDA market auction in local market. Potential sellers submit their AP_{DGx}: AP_{DG1} and AP_{DG2} to sell one unit goods, and potential buyers simultaneously submit their BP_{LDCx}: BP_{LDC1} and BP_{LDC2} to purchase one unit of goods, to the aggregator (acting as an auctioneer). The auctioneer matches potential seller and buyers and declares the market clearing prices in local market based on CDA market clearing algorithm as follows:

i. Matches the potential seller and buyer. The bid price must be greater than ask price for any match. The bid that shows the highest willingness-to-buy is matched with the respective quantity of those asks that state the lowest willingness-to-sell. This is repeated with the remaining bids until their willingness-to-buy does not any longer exceed or equal the willingness-to-sell of yet unmatched bids. All the remaining bids and asks cannot be allocated because the stated willingness-to-sell does not exceed the stated willingness-to-buy. In order to avoid this, in the present work, the ask prices are restricted between GBP and WALP, whereas the bid prices are restricted within WALP and GSP.
ii. Calculates the MCP_{Sx} as the weighted average of matched pairs of buy and ask prices:

$$MCP_{Sx} = \mathrm{MCP}_{\mathrm{DGx}} = \mathrm{MCP}_{\mathrm{LDCx}} = \frac{\mathrm{AP}_{\mathrm{DGx}} + \mathrm{BP}_{\mathrm{LDCx}}}{2} \tag{1}$$

The power imbalance (surplus/deficit), if any, in the local market will be transferred to second phase (global) market to achieve power balance in microgrid.

2.2. Global Market

In the proposed MEMF, two energy trade mechanisms are designed for global market auction.

i. In the first mechanism, grid will sell/buy power at limiting prices (fixed prices as in [14,25]) of the grid (GSP and GBP).
ii. In the second mechanism, grid selling/buying power prices vary based on ΔP_{LDCx} and limiting prices of the grid. The MCGSP/MCGBP are calculated as:

$$\Delta\mathrm{P}_{\mathrm{LDCx}} = \frac{\mathrm{MCMGP}_{\mathrm{LDCx}}}{\mathrm{LDCx}_{\mathrm{TL}}} \tag{2}$$

$$\left\{\begin{array}{c} If \quad \Delta\mathrm{P}_{\mathrm{LDCx}} = 1 \\ \mathrm{MCGSP} = \left\{\frac{(\mathrm{GSP+GBP})}{2}\right\} \\ \mathrm{MCGBP} = \left\{\frac{(\mathrm{GSP+GBP})}{2}\right\} \\ If \quad \Delta\mathrm{P}_{\mathrm{LDCx}} < 1 \\ \mathrm{MCGSP} = \left\{[1 + (1-\Delta\mathrm{P}_{\mathrm{LDCx}})^2]\left\{\frac{(\mathrm{GSP+GBP})}{2}\right\}\right\} \\ \mathrm{MCGBP} = \{[1 + (1-\Delta\mathrm{P}_{\mathrm{LDCx}})^2]\ \mathrm{GBP}\} \\ If \quad \Delta\mathrm{P}_{\mathrm{LDCx}} > 1 \\ \mathrm{MCGSP} = \left\{\frac{(\mathrm{GSP+GBP})}{2}\right\} \\ \mathrm{MCGBP} = \left\{[1 - (1-\Delta\mathrm{P}_{\mathrm{LDCx}})^2]\left\{\frac{(\mathrm{GSP+GBP})}{2}\right\}\right\} \end{array}\right\} \tag{3}$$

In this work, MCGSP is limited between WALP and GSP; and MCGBP is limited to be within GBP and WALP.

3. Linear Bidding Algorithm

In this work, a novel linear bidding algorithm is developed to decide asks and bid prices of stake holders. The linear bidding algorithm uses the concept of two-point line equation [36]. The two point's form of the equation for a line can describe any non vertical line in the Cartesian plane given the coordinates of two points which lie on the line.

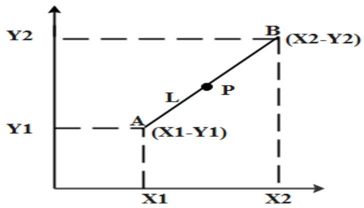

Fig.1. Stright line in a plane

- Let the line L passes through two given points $A(x_1,y_1)$ and $B(x_2,y_2)$.
- Let $P(x,y)$ be a general point on L.
- The three points A,B and P are collinear, therefore, we have
  Slope of AP = Slope of BP
  i.e.

$$\frac{y-y_1}{x-x_1} = \frac{y_2-y_1}{x_2-x_1} \tag{4}$$

- Thus equation of a straight line passing through points $A(x_1,y_1)$ and $B(x_2,y_2)$ can be written as:

$$y-y_1 = \frac{y_2-y_1}{x_2-x_1}(x-x_1) \tag{5}$$

The linear bidding algorithm uses equation (5) with different constraints to decide ask prices and bid prices of the stake holder for day-ahead trade intervals.

i. The AP_{DGx} for day-ahead trade intervals depends on limiting prices of grid, C_{DGx} and GP_{DGx}. To fix AP_{DGx}, (5) is modified as:

$$AP_{DGx} - GBP = \left\{ \left[\frac{(WALP - GBP)}{(C_{DGx} - 0.5C_{DGx})} \right] * \atop (GP_{DGx} - 0.5C_{DGx}) \right\} \tag{6}$$

AP_{DGx} of DGx is varied between C_{DGx} and 50% of C_{DGx} from WALP to GBP. If P_{DGi} of DGx is lesser than 50% of C_{DGx}, then AP_{DGx} is limited to GBP.

ii. BP_{LDCx} for day-head trade intervals depends on limiting prices of grid, MD_{LDCx} and day-ahead real-time $LDCx_{TL}$. To fix BP_{LDCx},(5) is modified as:

$$BP_{LDCx} - GSP = \left\{ \left[\frac{(WALP - GSP)}{(MD_{LDCx} - 0.5MD_{LDCx})} \right] * \atop (LDCx_{TL} - 0.5MD_{LDCx}) \right\} \tag{7}$$

BP_{LDCx} of LDCx is varied between MD_{LDCx} and 50% of MD_{LDCx} from WALP to GSP. If $LDCx_{TL}$ of LDCx is lesser than 50% of MD_{LDCx}, then BP_{LDCx} is limited to GSP.

In this algorithm, AP_{DGx} of DGx is restricted to be within GBP and weighted average of limiting prices of grid; and BP_{LDCx} of LDCx are in between weighted average of limiting prices of grid and GSP, to match all potential seller and buyers in the market auction.

4. Multi-Agent System Architecture and DR Options

4.1 The Multi-Agent System Architecture:

The proposed MAS architecture to conduct market auction and embed DR in to the smart DN is shown in Fig.2. The MAS is modeled as two layers of agents: (i) Organizational layer and (ii) Perception layer. The Organizational layer is designed to: (i) monitor in real-time, output powers of DG units and their ask prices, (ii) monitor the total load demand of LDCs, and their bid prices (iii) monitor the limiting prices of the grid (iv) match seller and buyer using CDA protocol (v) calculate the market clearing price of local and global market, and (vi) generate action signal for agents in perception layers to achieve power balance in the DN. The Perception layer is responsible to control the loads connected in the DN based on the action signals generated by organizational layer and requirements of the customer. M-function in MATLAB is used to develop the proposed MAS architecture.

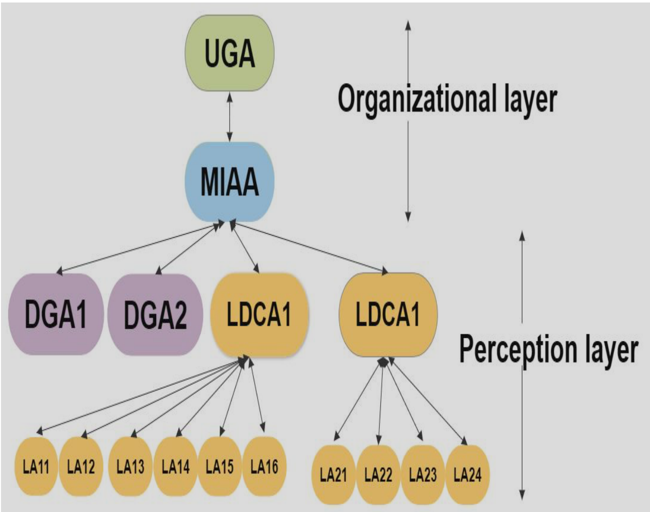

Fig. 2. The MAS architecture

The organizational layer consists of MIAA and UGA. The perception layer comprises of DGAx, LDCAx and LAxy. These agents perceive information from the concerned environment. These agents have interlayer communication among each other. The functions of the different agents are as follows:

A. Utility Grid Agent: UGA is in the organizational layer and it holds GSP and GBP of the grid power, and informs the same to MIAA to conduct market auction. It continuously monitors the imbalance condition of the microgrid, and is responsible for purchasing/selling surplus/deficit of power from/to microgrid at the global market cleared prices.

B. Microgrid Intelligent Aggregator Agent: This agent is in the organizational layer and is responsible for market auctions taken up in the microgrid.

The MIAA will:

- Collect the grid limiting prices (GSP and GBP) from UGA and communicates the same to DGAx and LDCAx participating in the local market to decide their ask and bid prices for day-ahead trading intervals.
- Collects day-ahead ask and bid prices from stake holders to match potential sellers (DGA1 and DGA2) and buyers (LDCA1 and LDCA2), and computes MCP_{Sx} using CDA market trade mechanism.

$$MCMGP_{LDCx} = GP_{DGx} \text{ of CDA matched DGx} \quad (8)$$

- Continuously monitor the real-time ΔP_{LDCx}. If possible, MIAA will achieve the power balance in the DN within the local market using DR options; otherwise MIAA will initiate global market auction, and communicate the same to respective Perception layer agents.
- Collect day-ahead GP_{DGx} of all DGx to compute P_{MG}.

$$P_{MG} = \sum_{x=1}^{n} P_{DGx} \quad (9)$$

- Collect day-ahead $LDCx_{TL}$ of all LDCx to compute TL_{MG}.

$$TL_{MG} = \sum_{x=1}^{n} LDCx_{TL} \quad (10)$$

- Compute $GLSP_{DGx}$, which is the surplus power in local market.

$$GLSP_{DGx} = \left[\begin{matrix} GP_{DGx} - \\ (LDCx_{TL} \text{ of CDA matched } LDC_x) \end{matrix}\right] \quad (11)$$

- Compute $GLBP_{LDCx}$ to meet the load requirement (which is not met by local market) of LDCx .

$$GLBP_{LDCx} = \left[\begin{matrix} LDCx_{TL} - \\ (GP_{DGx} \text{ of CDA matched DGx}) \end{matrix}\right] \quad (12)$$

Based on two phase (local and global) market auctions, MIAA Compute:

- $MGSP_{UG}/MGBP_{UG}$ after achieving balance condition in microgrid and SP_{MG}/BP_{MG} .The $MGSP_{UG}/MGBP_{UG}$ is the buying/selling power of the grid from/to MG.

$$MGSP_{UG} = (P_{MG} - TL_{MG}) \quad (13)$$

$$MGBP_{UG} = (TL_{MG} - P_{MG}) \quad (14)$$

$$SP_{MG} = \frac{\left\{\begin{matrix} [(\sum_{x=1}^{n} GLSP_{DGx}) - (\sum_{x=1}^{n} GLBP_{LDCx})] * \\ \frac{(\sum_{x=1}^{n} GLSP_{DGx} * MCGBP)}{(\sum_{x=1}^{n} GLSP_{DGx})} \end{matrix}\right\}}{[(\sum_{x=1}^{n} GLSP_{DGx}) - (\sum_{x=1}^{n} GLBP_{LDCx})]} \quad (15)$$

$$BP_{MG} = \frac{\left\{\begin{matrix} [(\sum_{x=1}^{n} GLBP_{LDCx}) - (\sum_{x=1}^{n} GLSP_{DGx})] * \\ \frac{(\sum_{x=1}^{n} GLBP_{LDCx} * MCGSP)}{(\sum_{x=1}^{n} GLBP_{LDCx})} \end{matrix}\right\}}{[(\sum_{x=1}^{n} GLBP_{LDCx}) - (\sum_{x=1}^{n} GLSP_{DGx})]} \quad (16)$$

- $MCSP_{DGx}$ and $MCBP_{LDCx}$.

i. When grid sell/buy power at GSP/GBP

$$MCSP_{DGx} = \frac{\left\{\begin{matrix} \left[\begin{matrix} (GP_{DGx} - GLSP_{DGx}) * \\ MCP_{DGx} \end{matrix}\right] + \\ (GLSP_{DGx} * GBP) \end{matrix}\right\}}{GP_{DGx}} \quad (17)$$

$$MCBP_{LDCx} = \frac{\left\{\begin{matrix} \left[\begin{matrix} (LDCx_{TL} - GLBP_{LDCx}) * \\ MCP_{LDCx} \end{matrix}\right] + \\ (GLBP_{LDCx} * GSP) \end{matrix}\right\}}{LDCx_{TL}} \quad (18)$$

ii. When grid sell/buy power at MCGSP/MCGBP

$$MCSP_{DGx} = \frac{\left\{\begin{matrix} [(GP_{DGx} - GLSP_{DGx}) * MCP_{DGx}] + \\ (GLSP_{DGx} * MCGBP) \end{matrix}\right\}}{GP_{DGx}} \quad (19)$$

$$MCBP_{LDCx} = \frac{\left\{\begin{matrix} [(LDCx_{TL} - GLBP_{LDCx}) * MCP_{LDCx}] + \\ (GLBP_{LDCx} * MCGSP) \end{matrix}\right\}}{LDCx_{TL}} \quad (20)$$

- $MIAP_{TI}$:

i. When $\sum_{x=1}^{n} GLBP_{LDCx} > \sum_{x=1}^{n} GLSP_{DGx}$

- When grid sell/buy power at its limiting prices

$$MIAP_{TI} = \left\{\begin{matrix} \sum_{x=1}^{n}(GLBP_{LDCx} * GSP) - \\ \left\{\begin{matrix} \left[\begin{matrix} \left(\sum_{x=1}^{n} GLBP_{LDCx} - \sum_{x=1}^{n} GLSP_{DGx}\right) * \\ GSP \end{matrix}\right] + \\ \left(\sum_{x=1}^{n} GLSP_{DGx} * GBP\right) \end{matrix}\right\} \end{matrix}\right\} * \beta \quad (21)$$

- When grid sell/buy power at MCGSP/MCGBP

$$MIAP_{TI} = \left\{\begin{matrix} \sum_{x=1}^{n}(GLBP_{LDCx} * MCGSP) - \\ \left\{\begin{matrix} \left[\begin{matrix} \left(\sum_{x=1}^{n} GLBP_{LDCx} - \sum_{x=1}^{n} GLSP_{DGx}\right) * \\ MCGSP \end{matrix}\right] + \\ \left(\sum_{x=1}^{n} GLSP_{DGx} * MCGBP\right) \end{matrix}\right\} \end{matrix}\right\} * \beta \quad (22)$$

ii. When $\sum_{x=1}^{n} GLBP_{LDCx} < \sum_{x=1}^{n} GLSP_{DGx}$

- When grid sell/buy power at its limiting prices

$$\mathrm{MIAP_{TI}} = \left\{ \begin{matrix} \left\{ \begin{matrix} \left[\left(\sum_{x=1}^{n} \mathrm{GLSP_{DGx}} - \sum_{x=1}^{n} \mathrm{GLBP_{LDCx}} \right) * \\ \mathrm{GBP} \right] + \\ \left(\sum_{x=1}^{n} \mathrm{GLBP_{DGx}} * \mathrm{GSP} \right) \end{matrix} \right\} - \\ \sum_{x=1}^{n} (\mathrm{GLSP_{DGx}} * \mathrm{GBP}) \end{matrix} \right\} * \beta \quad (23)$$

- When grid sell/buy power at MCGSP/MCGBP

$$\mathrm{MIAP_{TI}} = \left\{ \begin{matrix} \left\{ \begin{matrix} \left[\left(\sum_{x=1}^{n} \mathrm{GLSP_{DGx}} - \sum_{x=1}^{n} \mathrm{GLBP_{LDCx}} \right) * \\ \mathrm{MCGBP} \right] + \\ \left(\sum_{x=1}^{n} \mathrm{GLBP_{DGx}} * \mathrm{MCGSP} \right) \end{matrix} \right\} - \\ \sum_{x=1}^{n} (\mathrm{GLSP_{DGx}} * \mathrm{MCGBP}) \end{matrix} \right\} * \beta \quad (24)$$

Where, β is number of hours in a one-time interval.

C. *Distribution Generation Agent:* The DGAx are in the Perception layer and they perceive the generation information from their owners. As soon as the market is initialized, DGAx starts interacting with MIAA. In the initial stage of trading, DGAx receives limiting prices of the grid from the MIAA to decide the ask quotes (AP_{DGx}) which are to be placed in the market for day-ahead trading intervals using (6).

D. Load Distribution Center Agent and Load Agents: LDCAx are perception layer agents, representing the load entities (potential buyers) participating in the market. Each LDCAx represents a group of LA_{XY}. The subscript X and Y indicates an agent's locations and association in distribution center. The LDCAx: (i) supervise and control the connected loads, (ii) aggregates the information of the loads for which DR options are available, (iii) compute the bid quote prices using proposed linear bidding algorithm, and (iv) predict the load consumption of individual customers based on their history of consumption.

The LDCAx will:

- Collect the information about grid limiting prices from MIAA and perceives the load demand from LDCx to determine the bid quotes(BP_{LDCx}) using (7) which are to be placed in the market for day-ahead trading intervals.
- After local market auction, compute the real-time DLCF for all the customers connected to respective LDCAx. DLCF is introduced to allocate the available power ($MCMGP_{LDCx}$) of LDCAx to their aggregated customers. $DLCF_{LDCx}$ of respective LDCAx is based on $MCMGP_{LDCx}$ and MD_{LDCx}. The $DLCF_{LDCx}$ is determined as follows:

$$\left\{ \begin{matrix} If\ \mathrm{MCMGP_{LDCx}} < \mathrm{MD_{LDCx}} \\ \mathrm{DLCF_{LDCx}} = \dfrac{\mathrm{MCMGP_{LDCx}}}{\mathrm{MD_{LDCx}}} \\ If\ \mathrm{MCMGP_{LDCx}} \geq \mathrm{MD_{LDCx}} \\ \mathrm{DLCF_{LDCx}} = 1 \end{matrix} \right\} \quad (25)$$

- Then computes C_{CLP} for the LA_{XY} aggregated to respective LDCAx using,

$$\mathrm{C_{CLP}} = \text{Allotted Power of } \mathrm{LA_{XY}} * \mathrm{DLCF_{LDCx}} \quad (26)$$

- Communicates action signals (C_{CLP}, MCP_{LDCx}, GSP, GBP, MCGSP and MCGBP) to LA_{XY}.
- Work as DR agent, to receive and serve the DR options placed by LA_{XY} in the DN.

Based on these action signals, LA_{XY} will decide their power consumption level either by: (i) limiting customer power consumption within their C_{CLP}, or (ii) consuming the power according to their load requirement.

4.2 DR options

In the MEMF, LCP of a customer depends on market cleared prices of local and global markets. Customer participation on DR will also affect the LCP. In this work, a customer friendly DR options called capacity market, [37,38,39] is designed. Further, the control over the DR participation is provided to the customers rather than to the aggregator. Capacity market DR program will restrict the total power consumption level to the available supply within a given time frame. Individual customers are supplied with this reduced supply, and then load agents control the energizing of prioritized appliances (loads) of the customer with in their C_{CLP}. Suppose some part of power remains unused after energizing the prioritized loads, but which is not sufficient to energize the next preferred appliance. This amount of power will be automatically made available to the local center and is called GP_{AP}. A suitable incentive is offered to the customer for this power.

In the developed energy trade mechanism, as discussed in section 2, local market uses CDA protocol to clear the market, where as two trade mechanisms are designed for global market auction. In the first mechanism, grid will sell/buy power at limiting prices, and in the second mechanism, grid will sell/buy power at MCGSP/MCGBP. The market cleared LCP of the customer is determined as follows:

i. When grid is selling/buying power at its limiting prices (GSP and GBP) in the global market.
   - LCP of the customer participating in DR.

$$\mathrm{LCP_{with\ DR}} = \frac{\left\{ \begin{matrix} [(\mathrm{TL_{Lxy}} - \mathrm{GP_{AP}})\mathrm{MCP_{LDCx}}] + \\ (\mathrm{GP_{AP}} * \mathrm{GBP}) \end{matrix} \right\}}{\mathrm{TL_{Lxy}}} \quad (27)$$

➢ LCP of the customer not participating in DR.

$$\left\{\begin{array}{c} If \quad \mathrm{C_{CLP}} \geq \mathrm{TL_{Lxy}} \\ \mathrm{LCP_{Without\ DR}} = \mathrm{MCP_{LDCx}} \\ If \quad \mathrm{C_{CLP}} < \mathrm{TL_{Lxy}} \\ \mathrm{LCP_{Without\ DR}} = \dfrac{\left\{\begin{array}{c}(\mathrm{C_{CLP}} * \mathrm{MCP_{LDCx}}) + \\ \left[(\mathrm{TL_{Lxy}} - \mathrm{C_{CLP}}) * \mathrm{GSP}\right]\end{array}\right\}}{\mathrm{TL_{Lxy}}} \end{array}\right\} \quad (28)$$

ii. When grid sell/buy power at MCGSP/MCGBP in the global market.

➢ LCP of the customer participating in DR.

$$\mathrm{LCP_{with\ DR}} = \frac{\left\{\begin{array}{c}\left[(\mathrm{TL_{Lxy}} - \mathrm{GP_{AP}})\mathrm{MCP_{LDCx}}\right] + \\ (\mathrm{GP_{AP}} * \mathrm{MCGBP})\end{array}\right\}}{\mathrm{TL_{Lxy}}} \quad (29)$$

➢ LCP of the customer not participating in DR.

$$\left\{\begin{array}{c} If \quad \mathrm{C_{CLP}} \geq \mathrm{TL_{Lxy}} \\ \mathrm{LCP_{Without\ DR}} = \mathrm{MCP_{LDCx}} \\ If \quad \mathrm{C_{CLP}} < \mathrm{TL_{Lxy}} \\ \mathrm{LCP_{Without\ DR}} = \dfrac{\left\{\begin{array}{c}(\mathrm{C_{CLP}} * \mathrm{MCP_{LDCx}}) + \\ \left[(\mathrm{TL_{Lxy}} - \mathrm{C_{CLP}}) * \mathrm{MCGSP}\right]\end{array}\right\}}{\mathrm{TL_{Lxy}}} \end{array}\right\} \quad (30)$$

5. Market Simulation and Result Analysis

For validating the proposed MEMF architecture and the market algorithms a test smart distribution system is used. The test DN is a grid-tied microgrid system incorporating all the features of a real system, as shown in Fig.3. The integrated system is simulated using MATLAB/SIMULINK.

The grid-tied microgrid consists of: (i) MIAA as an aggregator for managing and trading power in the microgrid, (ii) two representative DG units, DG1 and DG2 with a total installed capacity of 100kW each, (iii) two LDCs, LDC1 and LDC2 with a maximum load of 100kW each. LDC1 is an aggregation of six smart homes/customers with controllable loads. A specified total power is allocated to each of the customer (L_{11}=L_{13}=L_{16}=20kW, L_{14}=10kW and L_{12}=L_{15}=15kW). Similarly LDC2 consists of four customers (L_{21}=20kW,L_{22}=30kW and L_{23}=L_{24}=25kW).

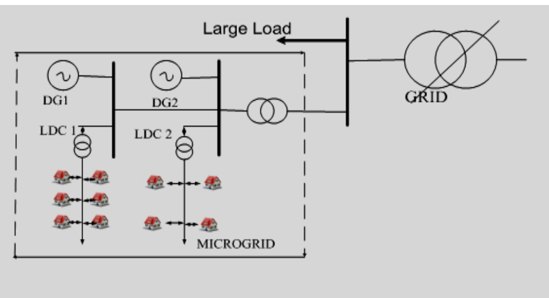

Fig.3. Test distribution network (grid-tied smart microgrid)

In this study, a day is divided into six time intervals of four hours each for taking market auction. The duration of the time blocks can be varied if necessary.

For the case study, following assumptions are made:

1. Limiting prices of the grid i.e. GSP is taken as 13.5 INR (Indian Rupees)/kWh and GBP is taken as 9 INR/ kWh.
2. L_{15} and L_{16} in LDC1 are having low priority appliances of total capacity 28kW and L_{21} and L_{22} in LDC2 are having low priority appliances of total capacity 41kW.

The Table 1 tabulate the generation of DGx, load profiles of LDCx and load requirement of customers connected to respective LDCs of the test system from time interval 1 to 6. The mismatch column of the Table 1 indicates surplus/deficit power in the corresponding interval. The values are selected so that, both local market and, at least some of the trading agents, are forced to participate in global market transactions are initiated.

Table 1. Generation and Load Data for Case Studies

Int.	DG1 (kW)	DG2 (kW)	LDC1 (kW)							LDC2 (kW)					MIS-MATCH (kW)
			L_{11}	L_{12}	L_{13}	L_{14}	L_{15}	L_{16}	TP	L_{21}	L_{22}	L_{23}	L_{24}	TP	
1	80	70	12	9	12	6	9	12	60	16	24	20	20	80	+10
2	90	70	20	15	20	10	15	20	100	16	24	20	20	80	-20
3	80	90	20	15	20	10	15	20	100	12	18	15	15	60	+10
4	70	80	20	15	20	10	15	20	100	20	30	25	25	100	-50
5	90	60	16	12	16	8	12	16	80	16	24	20	20	80	-10
6	30	70	12	9	12	6	9	12	60	20	30	25	25	100	-60

#: + sign indicates surplus and – sign indicates deficits

To analyze the market behaviour under dynamic power balance conditions, two market scenarios are simulated.

1. **Case 1:** In this case, to clear the market auction, the trade mechanism uses CDA protocol in the local market, and the grid will buy/sell power at its fixed limiting prices (GSP/GBP) in the global market. In addition, the market behaviour without DR and with DR options are simulated and analyzed.

a. *Market simulation without DR:* Here, none of the customers in the distribution network have opted DR. The load clearing of the customers in the DN is as follows:
   - ➢ If the TL_{Lxy} of a customer is within their C_{CLP}, then all the required loads are cleared for that customer.
   - ➢ In case, TL_{Lxy} of the customer is more than their C_{CLP}, then LAxy will meet the customer load requirement by initiating purchasing the additional power from the global market. For this case, the LCP of customer is calculated by using (28).
   - ➢ In case of surplus/deficit power in the microgrid, then MIAA will initiate global market to sweep out the imbalance condition at the grid limiting prices.

Table 2 shows the Market auction trading details with respect to DGx and LDCx in Case 1 without DR. Table 3 shows the share of local and global market auctions on load consumption of customers connected to the respective LDCx.

From the Table 2, it is observed that, during the time interval 1, DGA2 initiate MIAA to sell its surplus power in global market at GBP. During the time intervals 2,4 and 6, LDCA1 and LDCA2 will initiate MIAA to purchase their deficit power from the global market at GSP. During the time interval 3, DGA1 initiate MIAA to sell its surplus power in global market and LDC1 initiate MIAA to purchase its deficit power from global market. In this case, MIAA meet the additional load requirement of LDC1 from available surplus power of DG1 at GSP and sell the remaining surplus power of DG1 in global market at GBP. During the time interval 5, DGA1 initiate MIAA to sell its surplus power in global market and LDCA1 initiate MIAA to purchase its deficit power from global market; in this case MIAA will meet the additional load requirement of LDC1 from available surplus power of DG1 at GSP and purchase the remaining deficit power of LDC1 from global market at GSP. From the column $MIAP_{TI}$, it is observed that, during the time intervals 3 and 5, MIAA will sell/buy the deficit/surplus power of the stake holders to/from the grid in global market. MIAA makes profit, when there is both surplus and deficit power in stake holders after CDA trade auction in the local market. Otherwise, MIAA act as a mediator to exchange the power between stake holders and the grid at the market cleared prices in global market.

b. *Market simulation with DR:* In this case, L_{15} and L_{16} in LDC1, and L_{21} and L_{22} in LDC2 have opted capacity market DR. Load clearing of the customers in the DN is as follows:
   - All the loads of the customers are cleared if the C_{CLP} is sufficient to meet the present load.
   - In case of deficiency, (i) LA_{XY} of DR participating customer limits their consumption to C_{CLP}. The loads are supplied based on the set priority. For this case, the LCP of a customer is calculated by using (27). (ii) LA_{XY} of non DR participating customer will meet the customer load requirement by initiating purchasing the additional power from the global market. In this case, the LCP of the customer is calculated by using (28).

Table 4 shows the Market auction trading details with respect to DGx and LDCx in Case 1 with DR and Table 5 shows the share of local and global market auctions on load consumption of the customers connected to respective LDCx.

From Tables 4 and 5, it is observed that, market auction of the trading agents and load clearing of the customers in time interval 1 is similar to Case1-without DR. During the time intervals 2 to 6, due to the effect of DR participation of the customers, there is a substantial reduction in the level of global participation.

2. **Case 2:** In this case, to clear the market auction, the trade mechanism uses CDA protocol in the local market, and the grid transaction prices vary based on the ΔP_{LDCx} and limiting prices of grid. The grid selling price is now MCGSP and grid buying price is MCGBP. Again, in Case 2 also, the market behaviour without DR and with DR options are simulated and analyzed.

a. *Market simulation without DR:* In this case, market auction of the trading agents and load clearing of the customers are similar to Case 1 market simulation without DR, except LCP of customer is calculated by using (30).

Table 6 shows the Market auction trading details with respect to DGx and LDCx in Case 2 without DR, and Table 7 shows the share of local and global market auctions on load consumption of customer connected to respective LDCx.

b. *Market simulation with DR:* Here, market auction of the trading agents and load clearing of the customers in the DN are similar to Case 1 market simulation with DR, except that LCP of DR participating customer is calculated by using (29), and that of non participating customer is calculated by using (30).

Table.8 shows the Market auction trading details with respect to DGx and LDCx in Case 2-with DR, and Table 9 shows the share of local and global market auctions on load consumption of customers connected to respective LDCx.

The supply and demand curves and microgrid import/export power from/to grid, before and after executing DR program are shown in Fig. 4 and 5. From Fig.4 and Fig.5, it is observed that: during the time interval 1, before and after execution of DR program, the total load consumption of the microgrid is 140kW and selling power to grid is 10kW. In the time interval 2, load consumption of microgrid is 180kW and importing power from grid is 20kW before execution of DR program; and the corresponding values are 163kW and 3kW, after execution of DR program. The details of these values are summarized in Figs. 4 and 5. Clearly, the MEMF is very effective in reducing supply-demand gap of the microgrid and dependency on the grid.

Figure 6 to 9 depicts the comparison of ask/bid prices and market cleared prices in the two cases of without and with DR options. It can be noted from these figures that, the proposed linear bidding algorithm and second energy trade mechanism in global market auction are beneficiary for the stake holders as these will improve their profit margin. e.g.: in Fig.6, during the time interval 3 (for the seller), AP_{DG1} of DG1 before and after the execution of DR program in both the cases is 10.35 INR/kWh. $MCSP_{DG1}$ before the execution of DR program in Case 1 is 11.025 INR/kWh and in Case 2 is 11.27 INR/kWh, and after the execution of DR program in

Table 2. Case 1-Trading details of the microgrid without DR

Int.	Market	DG1*	DG2*	Market	LDC1*	LDC2*	MG*E/I (price)	MIAP$_{TI}$
1	GP_{DGx}/AP_{DGx}	80/10.35	70/9.9	LD_{LDCx}/BP_{LDCx}	60/13.05	80/12.15	-10/9	0
	Local/MCP_{DGx}	80/11.25	60/11.48	Local/MCP_{LDCx}	60/11.48	80/11.25		
	Global/GBP		10/9	Global/GSP				
	$GP_{DGx}/MCSP_{DGx}$	80/11.25	70/11.12	$LD_{LDCx}/MCBP_{LDCx}$	60/11.48	80/11.25		
2	GP_{DGx}/AP_{DGx}	90/10.8	70/9.9	LD_{LDCx}/BP_{LDCx}	100/11.25	80/12.15	+20/13.5	0
	Local/MCP_{DGx}	90/11.03	70/11.03	Local/MCP_{LDCx}	90/11.03	70/11.03		
	Global/GBP			Global/GSP	10/13.5	10/13.5		
	$GP_{DGx}/MCSP_{DGx}$	90/11.03	70/11.03	$LD_{LDCx}/MCBP_{LDCx}$	100/11.28	80/11.39		
3	GP_{DGx}/AP_{DGx}	80/10.35	90/10.8	LD_{LDCx}/BP_{LDCx}	100/11.25	60/13.05	-10/9	180
	Local/MCP_{DGx}	60/11.7	90/11.03	Local/MCP_{LDCx}	90/11.03	60/11.7		
	Global/GBP	20/9		Global/GSP	10/13.5			
	$GP_{DGx}/MCSP_{DGx}$	80/11.025	90/11.03	$LD_{LDCx}/MCBP_{LDCx}$	100/11.28	60/11.7		
4	GP_{DGx}/AP_{DGx}	70/9.9	80/10.35	LD_{LDCx}/BP_{LDCx}	100/11.25	100/11.25	+50/13.5	0
	Local/MCP_{DGx}	70/10.57	80/10.8	Local/MCP_{LDCx}	70/10.57	80/10.8		
	Global/GBP			Global/GSP	30/13.5	20/13.5		
	$GP_{DGx}/MCSP_{DGx}$	70/10.57	80/10.8	$LD_{LDCx}/MCBP_{LDCx}$	100/11.45	100/11.34		
5	GP_{DGx}/AP_{DGx}	90/10.8	60/9.45	LD_{LDCx}/BP_{LDCx}	80/12.15	80/12.15	+10/13.5	180
	Local/MCP_{DGx}	80/11.48	60/10.8	Local/MCP_{LDCx}	60/10.8	80/11.48		
	Global/GBP	10/9		Global/GSP	20/13.5			
	$GP_{DGx}/MCSP_{DGx}$	90/11.20	60/10.8	$LD_{LDCx}/MCBP_{LDCx}$	80/11.47	80/11.48		
6	GP_{DGx}/AP_{DGx}	30/9	70/9.9	LD_{LDCx}/BP_{LDCx}	60/13.05	100/11.25	+60/13.5	0
	Local/MCP_{DGx}	30/11.03	70/10.57	Local/MCP_{LDCx}	30/11.03	70/10.57		
	Global/GBP			Global/GSP	30/13.5	30/13.5		
	$GP_{DGx}/MCSP_{DGx}$	30/11.03	70/10.57	$LD_{LDCx}/MCBP_{LDCx}$	60/12.26	100/11.45		

*: Units for market share are in kilowatts, price is in INR/kWh, #: + sign indicates Import from grid and – sign indicates Export to grid

Table 3. Case 1-Load details of residential loads connected to respective LDCx without DR.

Int	LDC1									LDC2						
	$MCMGP_{LDC1}$ (MCP_{LDC1})	£		L_{11}* (P)	L_{12}* (P)	L_{13}* (P)	L_{14}* (P)	L_{15}* (P)	L_{16}* (P)	$MCMGP_{LDC2}$ (MCP_{LDC2})	£		L_{21}* (P)	L_{22}* (P)	L_{23}* (P)	L_{24}* (P)
1	70 (11.48)	0.7	C_{CLP} (MCP_{LDC1})	14 (11.48)	10.5 (11.48)	14 (11.48)	7 (11.48)	10.5 (11.48)	14 (11.48)	80 (11.25)	0.8	C_{CLP} (MCP_{LDC2})	16 (11.25)	24 (11.25)	20 (11.25)	20 (11.25)
			TL_{Lxy} (LCP_{Lxy})	12 (11.48)	9 (11.48)	12 (11.48)	6 (11.48)	9 (11.48)	12 (11.48)			TL_{Lxy} (LCP_{Lxy})	16 (11.25)	24 (11.25)	20 (11.25)	20 (11.25)
			GL (GSP/GBP)									GL (GSP/GBP)				
2	90 (11.03)	0.9	C_{CLP} (MCP_{LDC1})	18 (11.03)	13.5 (11.03)	18 (11.03)	9 (11.03)	13.5 (11.03)	18 (11.03)	70 (11.03)	0.7	C_{CLP} (MCP_{LDC2})	14 (11.03)	21 (11.03)	17.5 (11.03)	17.5 (11.03)
			TL_{Lxy} (LCP_{Lxy})	20 (11.28)	15 (11.28)	20 (11.28)	10 (11.28)	15 (11.28)	20 (11.28)			TL_{Lxy} (LCP_{Lxy})	16 (11.39)	24 (11.39)	20 (11.39)	20 (11.39)
			GL (GSP/GBP)	+2 (13.5)	+1.5 (13.5)	+2 (13.5)	+1 (13.5)	+1.5 (13.5)	+2 (13.5)			GL (GSP/GBP)	+2 (13.5)	+3 (13.5)	+2.5 (13.5)	+2.5 (13.5)
3	90 (11.03)	0.9	C_{CLP} (MCP_{LDC1})	18 (11.03)	13.5 (11.03)	18 (11.03)	9 (11.03)	13.5 (11.03)	18 (11.03)	80 (11.7)	0.8	C_{CLP} (MCP_{LDC2})	16 (11.7)	24 (11.7)	20 (11.7)	20 (11.7)
			TL_{Lxy} (LCP_{Lxy})	20 (11.28)	15 (11.28)	20 (11.28)	10 (11.28)	15 (11.28)	20 (11.28)			TL_{Lxy} (LCP_{Lxy})	12 (11.7)	18 (11.7)	15 (11.7)	15 (11.7)
			GL (GSP/GBP)	+2 (13.5)	+1.5 (13.5)	+2 (13.5)	+1 (13.5)	+1.5 (13.5)	+2 (13.5)			GL (GSP/GBP)				
4	70 (10.57)	0.7	C_{CLP} (MCP_{LDC1})	14 (10.57)	10.5 (10.57)	14 (10.57)	7 (10.57)	10.5 (10.57)	14 (10.57)	80 (10.8)	0.8	C_{CLP} (MCP_{LDC2})	16 (10.8)	24 (10.8)	20 (10.8)	20 (10.8)
			TL_{Lxy} (LCP_{Lxy})	20 (11.45)	15 (11.45)	20 (11.45)	10 (11.45)	15 (11.45)	20 (11.45)			TL_{Lxy} (LCP_{Lxy})	20 (11.34)	30 (11.34)	25 (11.34)	25 (11.34)
			GL (GSP/GBP)	+6 (13.5)	+4.5 (13.5)	+6 (13.5)	+3 (13.5)	+4.5 (13.5)	+6 (13.5)			GL (GSP/GBP)	+4 (13.5)	+6 (13.5)	+5 (13.5)	+5 (13.5)
5	60 (10.8)	0.6	C_{CLP} (MCP_{LDC1})	12 (10.8)	9 (10.8)	12 (10.8)	6 (10.8)	9 (10.8)	12 (10.8)	90 (11.48)	0.9	C_{CLP} (MCP_{LDC2})	18 (11.48)	27 (11.48)	22.5 (11.48)	22.5 (11.48)
			TL_{Lxy} (LCP_{Lxy})	16 (11.47)	12 (11.47)	16 (11.47)	8 (11.47)	12 (11.47)	16 (11.47)			TL_{Lxy} (LCP_{Lxy})	16 (11.25)	24 (11.25)	20 (11.25)	20 (11.25)
			GL (GSP/GBP)	+4 (13.5)	+3 (13.5)	+4 (13.5)	+2 (13.5)	+3 (13.5)	+4 (13.5)			GL (GSP/GBP)				
6	30 (11)	0.3	C_{CLP} (MCP_{LDC1})	6 (11)	4.5 (11)	6 (11)	3 (11)	4.5 (11)	6 (11)	70 (10.57)	0.7	C_{CLP} (MCP_{LDC2})	14 (10.57)	21 (10.57)	17.5 (10.57)	17.5 (10.57)
			TL_{Lxy} (LCP_{Lxy})	12 (12.25)	9 (12.25)	12 (12.25)	6 (12.25)	9 (12.25)	12 (12.25)			TL_{Lxy} (LCP_{Lxy})	20 (11.45)	30 (11.45)	25 (11.45)	25 (11.45)
			GL (GSP/GBP)	+6 (13.5)	+4.5 (13.5)	+6 (13.5)	+3 (13.5)	+4.5 (13.5)	+6 (13.5)			GL (GSP/GBP)	+6 (13.5)	+9 (13.5)	+7.5 (13.5)	+7.5 (13.5)

*: Units for market share are in kilowatts, **₱:**$MCMGP_{LDCX}$, **£:DLCF**, GL:Global Market.#: + /- sign indicates Import/ Export of power from/to grid

Table 4. Case 1-Trading details of microgrid with DR

Int.	Market	DG1*	DG2*	Market	LDC1*	LDC2*	MG*E/I (price)	$MIAP_{TI}$
1	GP_{DGx}/AP_{DGx}	80/10.35	70/9.9	LD_{LDCx}/BP_{LDCx}	60/13.05	80/12.15	-10/10.94	0
	$Local/MCP_{DGx}$	80/11.25	60/11.48	$Local/MCP_{LDCx}$	60/11.48	80/11.25		
	Global/GBP		10/10.94	Global/GSP				
	$GP_{DGx}/MCSP_{DGx}$	80/11.25	70/11.12	$LD_{LDCx}/MCBP_{LDCx}$	60/11.48	80/11.25		
2	GP_{DGx}/AP_{DGx}	90/10.8	70/9.9	LD_{LDCx}/BP_{LDCx}	93/11.56	70/12.6	+3/13.5	0
	$Local/MCP_{DGx}$	90/11.18	70/11.25	$Local/MCP_{LDCx}$	90/11.18	70/11.25		
	Global/GBP			Global/GSP	3/13.5			
	$GP_{DGx}/MCSP_{DGx}$	90/11.18	70/11.25	$LD_{LDCx}/MCBP_{LDCx}$	93/11.25	70/11.25		
3	GP_{DGx}/AP_{DGx}	80/10.35	90/10.8	LD_{LDCx}/BP_{LDCx}	93/11.56	70/12.6	-7/9	52
	$Local/MCP_{DGx}$	70/11.47	90/11.18	$Local/MCP_{LDCx}$	90/11.18	70/11.47		
	Global/GBP	10/9		Global/GSP	3/13.5			
	$GP_{DGx}/MCSP_{DGx}$	80/11.16	90/11.18	$LD_{LDCx}/MCBP_{LDCx}$	93/11.25	70/11.47		
4	GP_{DGx}/AP_{DGx}	70/9.9	80/10.35	LD_{LDCx}/BP_{LDCx}	93/11.56	80/12.15	+23/13.5	0
	$Local/MCP_{DGx}$	70/11.03	80/10.96	$Local/MCP_{LDCx}$	80/10.96	70/11.03		
	Global/GBP			Global/GSP	13/13.5	10/13.5		
	$GP_{DGx}/MCSP_{DGx}$	70/11.03	80/10.96	$LD_{LDCx}/MCBP_{LDCx}$	93/11.31	80/11.33		
5	GP_{DGx}/AP_{DGx}	90/10.8	60/9.45	LD_{LDCx}/BP_{LDCx}	73/12.46	80/12.15	+3/13.5	180
	$Local/MCP_{DGx}$	80/11.48	60/10.96	$Local/MCP_{LDCx}$	60/10.96	80/11.48		
	Global/GBP	10/9		Global/GSP	13/13.5			
	$GP_{DGx}/MCSP_{DGx}$	90/11.20	60/10.96	$LD_{LDCx}/MCBP_{LDCx}$	73/11.41	80/11.48		
6	GP_{DGx}/AP_{DGx}	30/9	70/9.9	LD_{LDCx}/BP_{LDCx}	46/13.5	80/12.15	+26/13.5	0
	$Local/MCP_{DGx}$	30/11.25	70/11.02	$Local/MCP_{LDCx}$	30/11.25	70/11.02		
	Global/GBP			Global/GSP	16/13.5	10/13.5		
	$GP_{DGx}/MCSP_{DGx}$	30/11.25	70/11.02	$LD_{LDCx}/MCBP_{LDCx}$	46/12.03	80/11.33		

Table 5. Case1-Load details of residential loads connected to respective LDCx with DR.

Int	LDC1									LDC2						
	$MCMGP_{LDC1}$ (MCP_{LDC1})	£		L_{11}* (P)	L_{12}* (P)	L_{13}* (P)	L_{14}* (P)	L_{15}* (P)	L_{16}* (P)	$MCMGP_{LDC2}$ (MCP_{LDC2})	£		L_{21}* (P)	L_{22}* (P)	L_{23}* (P)	L_{24}* (P)
1	70 (11.48)	0.7	C_{CLP} (MCP_{LDC1})	14 (11.48)	10.5 (11.48)	14 (11.48)	7 (11.48)	**10.5 (11.48)**	**14 (11.48)**	80 (11.25)	0.8	C_{CLP} (MCP_{LDC2})	**16 (11.25)**	**24 (11.25)**	20 (11.25)	20 (11.25)
			TL_{Lxy} (LCP_{Lxy})	12 (11.48)	9 (11.48)	12 (11.48)	6 (11.48)	**9 (11.48)**	**12 (11.48)**			TL_{Lxy} (LCP_{Lxy})	**16 (11.25)**	**24 (11.25)**	20 (11.25)	20 (11.25)
			GL (GSP/GBP)									GL (GSP/GBP)				
2	90 (11.18)	0.9	C_{CLP} (MCP_{LDC1})	18 (11.18)	13.5 (11.18)	18 (11.18)	9 (11.18)	**13.5 (11.18)**	**18 (11.18)**	70 (11.25)	0.7	C_{CLP} (MCP_{LDC2})	**14 (11.25)**	**21 (11.25)**	17.5 (11.25)	17.5 (11.25)
			TL_{Lxy} (LCP_{Lxy})	20 (11.41)	15 (11.41)	20 (11.41)	10 (11.41)	**12 (10.90)**	**16 (10.90)**			TL_{Lxy} (LCP_{Lxy})	**12 (10.87)**	**18 (10.87)**	20 (11.53)	20 (11.53)
			GL (GSP/GBP)	+2 (13.5)	+1.5 (13.5)	+2 (13.5)	+1 (13.5)	**-1.5 (9)**	**-2 (9)**			GL (GSP/GBP)	**-2 (9)**	**-3 (9)**	+2.5 (13.5)	+2.5 (13.5)
3	90 (11.18)	0.9	C_{CLP} (MCP_{LDC1})	18 (11.18)	13.5 (11.18)	18 (11.18)	9 (11.18)	**13.5 (11.18)**	**18 (11.18)**	80 (11.47)	0.8	C_{CLP} (MCP_{LDC2})	**16 (11.47)**	**24 (11.47)**	20 (11.47)	20 (11.47)
			TL_{Lxy} (LCP_{Lxy})	20 (11.41)	15 (11.41)	20 (11.41)	10 (11.41)	**12 (10.90)**	**16 (10.90)**			TL_{Lxy} (LCP_{Lxy})	**16 (11.47)**	**24 (11.47)**	15 (11.47)	15 (11.47)
			GL (GSP/GBP)	+2 (13.5)	+1.5 (13.5)	+2 (13.5)	+1 (13.5)	**-1.5 (9)**	**-2 (9)**			GL (GSP/GBP)				
4	80 (10.96)	0.8	C_{CLP} (MCP_{LDC1})	16 (10.96)	12 (10.96)	16 (10.96)	8 (10.96)	**12 (10.96)**	**16 (10.96)**	70 (11.03)	0.7	C_{CLP} (MCP_{LDC2})	**14 (11.03)**	**21 (11.03)**	17.5 (11.03)	20 (10.8)
			TL_{Lxy} (LCP_{Lxy})	20 (11.47)	15 (11.47)	20 (11.47)	10 (11.47)	**12 (10.96)**	**16 (10.96)**			TL_{Lxy} (LCP_{Lxy})	**12 (10.69)**	**18 (10.69)**	25 (11.77)	25 (11.77)
			GL (GSP/GBP)	+4 (13.5)	+3 (13.5)	+4 (13.5)	+2 (13.5)					GL (GSP/GBP)	**-2 (9)**	**-3 (9)**	+7.5 (13.5)	+7.55 (13.5)
5	60 (10.96)	0.6	C_{CLP} (MCP_{LDC1})	12 (10.96)	9 (10.96)	12 (10.96)	6 (10.96)	**9 (10.96)**	**12 (10.96)**	90 (11.48)	0.9	C_{CLP} (MCP_{LDC2})	**18 (11.48)**	**27 (11.48)**	22.5 (11.48)	22.5 (11.48)
			TL_{Lxy} (LCP_{Lxy})	16 (11.60)	12 (11.60)	16 (11.60)	8 (11.60)	**9 (10.96)**	**12 (10.96)**			TL_{Lxy} (LCP_{Lxy})	**16 (11.25)**	**24 (11.25)**	20 (11.25)	20 (11.25)
			GL (GSP/GBP)	+4 (13.5)	+3 (13.5)	+4 (13.5)	+2 (13.5)					GL (GSP/GBP)				
6	30 (11.25)	0.3	C_{CLP} (MCP_{LDC1})	6 (11.25)	4.5 (11.25)	6 (11.25)	3 (11.25)	**4.5 (11.25)**	**6 (11.25)**	70 (11.02)	0.7	C_{CLP} (MCP_{LDC2})	**14 (11.02)**	**21 (11.02)**	17.5 (11.02)	17.5 (11.02)
			TL_{Lxy} (LCP_{Lxy})	12 (12.37)	9 (12.37)	12 (12.37)	6 (12.37)	**3 (10.12)**	**12 (10.12)**			TL_{Lxy} (LCP_{Lxy})	**12 (10.68)**	**18 (10.68)**	25 (11.76)	25 (11.76)
			GL (GSP/GBP)	+6 (13.5)	+4.5 (13.5)	+6 (13.5)	+3 (13.5)	**-1.5 (9)**	**-2 (9)**			GL (GSP/GBP)	**-2 (9)**	**-3 (9)**	+7.5 (13.5)	+7.5 (13.5)

Table 6. Case 2-Trading details of microgrid without DR

Int.	Market	DG1*	DG2*	Market	LDC1*	LDC2*	MG*E/I (price)	$MIAP_{TI}$
1	GP_{DGx} /AP_{DGx}	80/10.35	70/9.9	LD_{LDCx}/ BP_{LDCx}	60/13.05	80/12.15	-10/10.94	0
	Local/MCP_{LCx}	80/11.25	60/11.48	Local/MCP_{LCx}	60/11.48	80/11.25		
	Global/MCGBP		10/10.94	Global/MCGSP				
	GP_{DGx} /$MCSP_{DGx}$	80/11.25	70/11.40	LD_{LDCx} /$MCBP_{LDCx}$	60/11.48	80/11.25		
2	GP_{DGx} /AP_{DGx}	90/10.8	70/9.9	LD_{LDCx}/ BP_{LDCx}	100/11.25	80/12.15	+20/11.40	0
	Local/MCP_{LCx}	90/11.03	70/11.03	Local/MCP_{LCx}	90/11.03	70/11.03		
	Global/MCGBP			Global/MCGSP	10/11.36	10/11.43		
	GP_{DGx} /$MCSP_{DGx}$	90/11.03	70/11.03	LD_{LDCx} /$MCBP_{LDCx}$	100/11.06	80/11.08		
3	GP_{DGx} /AP_{DGx}	80/10.35	90/10.8	LD_{LDCx}/ BP_{LDCx}	100/11.25	60/13.05	-10/10	54.4
	Local/MCP_{LCx}	60/11.7	90/11.03	Local/MCP_{LCx}	90/11.03	60/11.7		
	Global/MCGBP	20/10		Global/MCGSP	10/11.36			
	GP_{DGx} /$MCSP_{DGx}$	80/11.27	90/11.03	LD_{LDCx} /$MCBP_{LDCx}$	100/11.063	60/11.7		
4	GP_{DGx} /AP_{DGx}	70/9.9	80/10.35	LD_{LDCx}/ BP_{LDCx}	100/11.25	100/11.25	+50/12.04	0
	Local/MCP_{LCx}	70/10.57	80/10.8	Local/MCP_{LCx}	70/10.57	80/10.8		
	Global/MCGBP			Global/MCGSP	30/12.26	20/11.7		
	GP_{DGx} /$MCSP_{DGx}$	70/10.57	80/10.8	LD_{LDCx} /$MCBP_{LDCx}$	100/11.07	100/10.98		
5	GP_{DGx} /AP_{DGx}	90/10.8	60/9.45	LD_{LDCx}/ BP_{LDCx}	80/12.15	80/12.15	+10/11.95	35.2
	Local/MCP_{LCx}	80/11.48	60/10.8	Local/MCP_{LCx}	60/10.8	80/11.48		
	Global/MCGBP	10/11.07		Global/MCGSP	20/11.95			
	GP_{DGx} /$MCSP_{DGx}$	90/11.43	60/10.8	LD_{LDCx} /$MCBP_{LDCx}$	80/11.08	80/11.25		
6	GP_{DGx} /AP_{DGx}	30/9	70/9.9	LD_{LDCx}/ BP_{LDCx}	60/13.05	100/11.25	+60/12.88	0
	Local/MCP_{LCx}	30/11.03	70/10.57	Local/MCP_{LCx}	30/11.03	70/10.57		
	Global/MCGBP			Global/MCGSP	30/13.5	30/12.26		
	GP_{DGx} /$MCSP_{DGx}$	30/11.03	70/10.57	LD_{LDCx} /$MCBP_{LDCx}$	60/12.26	100/11.08		

Table 7. Case2-Load details of residential loads connected to respective LDCx without DR.

Int	LDC1									LDC2						
	$MCMGP_{LDC1}$ (MCP_{LDC1})	£		L_{11}* (P)	L_{12}* (P)	L_{13}* (P)	L_{14}* (P)	L_{15}* (P)	L_{16}* (P)	$MCMGP_{LDC2}$ (MCP_{LDC2})	£		L_{21}* (P)	L_{22}* (P)	L_{23}* (P)	L_{24}* (P)
1	70 (11.48)	0.7	C_{CLP} (MCP_{LDC1})	14 (11.48)	10.5 (11.48)	14 (11.48)	7 (11.48)	10.5 (11.48)	14 (11.48)	80 (11.25)	0.8	C_{CLP} (MCP_{LDC2})	16 (11.25)	24 (11.25)	20 (11.25)	20 (11.25)
			TL_{Lxy} (LCP_{Lxy})	12 (11.48)	9 (11.48)	12 (11.48)	6 (11.48)	9 (11.48)	12 (11.48)			TL_{Lxy} (LCP_{Lxy})	16 (11.25)	24 (11.25)	20 (11.25)	20 (11.25)
			GL(MCGSP/ MCGBP)									GL(MCGSP/ MCGBP)				
2	90 (11.03)	0.9	C_{CLP} (MCP_{LDC1})	18 (11.03)	13.5 (11.03)	18 (11.03)	9 (11.03)	13.5 (11.03)	18 (11.03)	70 (11.03)	0.7	C_{CLP} (MCP_{LDC2})	14 (11.03)	21 (11.03)	17.5 (11.03)	17.5 (11.03)
			TL_{Lxy} (LCP_{Lxy})	20 (11.06)	15 (11.06)	20 (11.06)	10 (11.06)	15 (11.06)	20 (11.06)			TL_{Lxy} (LCP_{Lxy})	16 (11.08)	24 (11.08)	20 (11.08)	20 (11.08)
			GL(MCGSP/ MCGBP)	+2 (11.36)	+1.5 (11.36)	+2 (11.36)	+1 (11.36)	+1.5 (11.36)	+2 (11.36))			GL(MCGSP/ MCGBP)	+2 (11.43)	+3 (11.43)	+2.5 (11.43)	+2.5 (11.43)
3	90 (11.03)	0.9	C_{CLP} (MCP_{LDC1})	18 (11.03)	13.5 (11.03)	18 (11.03)	9 (11.03)	13.5 (11.03)	18 (11.03)	80 (11.7)	0.8	C_{CLP} (MCP_{LDC2})	16 (11.7)	24 (11.7)	20 (11.7)	20 (11.7)
			TL_{Lxy} (LCP_{Lxy})	20 (11.06)	15 (11.06)	20 (11.06)	10 (11.06)	15 (11.06)	20 (11.06)			TL_{Lxy} (LCP_{Lxy})	12 (11.7)	18 (11.7)	15 (11.7)	15 (11.7)
			GL(MCGSP/ MCGBP)	+2 (11.36)	+1.5 (11.36)	+2 (11.36)	+1 (11.36)	+1.5 (11.36)	+2 (11.36))			GL(MCGSP/ MCGBP)				
4	70 (10.57)	0.7	C_{CLP} (MCP_{LDC1})	14 (10.57)	10.5 (10.57)	14 (10.57)	7 (10.57)	10.5 (10.57)	14 (10.57)	80 (10.8)	0.8	C_{CLP} (MCP_{LDC2})	16 (10.8)	24 (10.8)	20 (10.8)	20 (10.8)
			TL_{Lxy} (LCP_{Lxy})	20 (11.08)	15 (11.08)	20 (11.08)	10 (11.08)	15 (11.08)	20 (11.08)			TL_{Lxy} (LCP_{Lxy})	20 (10.98)	30 (10.98)	25 (10.98)	25 (10.98)
			GL(MCGSP/ MCGBP)	+6 (12.26)	+4.5 (12.26)	+6 (12.26)	+3 (12.26)	+4.5 (12.26)	+6 (12.26)			GL(MCGSP/ MCGBP)	+4 (11.7)	+6 (11.7)	+5 (11.7)	+5 (11.7)
5	60 (10.8)	0.6	C_{CLP} (MCP_{LDC1})	12 (10.8)	9 (10.8)	12 (10.8)	6 (10.8)	9 (10.8)	12 (10.8)	90 (11.48)	0.9	C_{CLP} (MCP_{LDC2})	18 (11.48)	27 (11.48)	22.5 (11.48)	22.5 (11.48)
			TL_{Lxy} (LCP_{Lxy})	16 (11.08)	12 (11.08)	16 (11.08)	8 (11.08)	12 (11.08)	16 (11.08)			TL_{Lxy} (LCP_{Lxy})	16 (11.25)	24 (11.25)	20 (11.25)	20 (11.25)
			GL(MCGSP/ MCGBP)	+4 (11.95)	+3 (11.95)	+4 (11.95)	+2 (11.95)	+3 (11.95)	+4 (11.95)			GL(MCGSP/ MCGBP)				
6	30 (11.0.3)	0.3	C_{CLP} (MCP_{LDC1})	6 (11.0.3)	4.5 (11.03)	6 (11.03)	3 (11.03)	4.5 (11.03)	6 (11.03)	70 (10.57)	0.7	C_{CLP} (MCP_{LDC2})	14 (10.57)	21 (10.57)	17.5 (10.57)	17.5 (10.57)
			TL_{Lxy} (LCP_{Lxy})	12 (12.26)	9 (12.26)	12 (12.26)	6 (12.26)	9 (12.26)	12 (12.26)			TL_{Lxy} (LCP_{Lxy})	20 (11.08)	30 (11.08)	25 (11.08)	25 (11.08)
			GL(MCGSP/ MCGBP)	+6 (13.5)	+4.5 (13.5)	+6 (13.5)	+3 (13.5)	+4.5 (13.5)	+6 (13.5)			GL(MCGSP/ MCGBP)	+6 (12.26)	+9 (12.26)	+7.5 (12.26)	+7.5 (12.26)

Table 8. Case 2-Trading details of microgrid with DR

Int.	Market	DG1*	DG2*	Market	LDC1*	LDC2*	MG*E/I (price)	$MIAP_{TI}$
1	GP_{DGx} /AP_{DGx}	80/10.35	70/9.9	LD_{LDCx}/ BP_{LDCx}	60/13.05	80/12.15	-10/10.94	0
	Local/MCP_{LCx}	80/11.25	60/11.48	Local/MCP_{LCx}	60/11.48	80/11.25		
	Global/MCGBP		10/10.94	Global/MCGSP				
	GP_{DGx} /$MCSP_{DGx}$	80/11.25	70/11.40	LD_{LDCx} /$MCBP_{LDCx}$	60/11.48	80/11.25		
2	GP_{DGx} /AP_{DGx}	90/10.8	70/9.9	LD_{LDCx}/ BP_{LDCx}	93/11.56	70/12.6	+3/11.26	0
	Local/MCP_{LCx}	90/11.18	70/11.25	Local/MCP_{LCx}	90/11.18	70/11.25		
	Global/MCGBP			Global/MCGSP	3/11.26			
	GP_{DGx} /$MCSP_{DGx}$	90/11.18	70/11.25	LD_{LDCx} /$MCBP_{LDCx}$	93/11.182	70/11.25		
3	GP_{DGx} /AP_{DGx}	80/10.35	90/10.8	LD_{LDCx}/ BP_{LDCx}	93/11.56	70/12.6	-7/11.02	2.88
	Local/MCP_{LCx}	70/11.47	90/11.18	Local/MCP_{LCx}	90/11.18	70/11.47		
	Global/MCGBP	10/11.02		Global/MCGSP	3/11.26			
	GP_{DGx} /$MCSP_{DGx}$	80/11.41	90/11.18	LD_{LDCx} /$MCBP_{LDCx}$	93/11.182	70/11.47		
4	GP_{DGx} /AP_{DGx}	70/9.9	80/10.35	LD_{LDCx}/ BP_{LDCx}	93/11.56	80/12.15	+23/11.45	0
	Local/MCP_{LCx}	70/11.03	80/10.96	Local/MCP_{LCx}	80/10.96	70/11.03		
	Global/MCGBP			Global/MCGSP	13/11.47	10/11.43		
	GP_{DGx} /$MCSP_{DGx}$	70/11.03	80/10.96	LD_{LDCx} /$MCBP_{LDCx}$	93/11.03	80/11.08		
5	GP_{DGx} /AP_{DGx}	90/10.8	60/9.45	LD_{LDCx}/ BP_{LDCx}	73/12.46	80/12.15	+3/11.61	21.6
	Local/MCP_{LCx}	80/11.48	60/10.96	Local/MCP_{LCx}	60/10.96	80/11.48		
	Global/MCGBP	10/11.07		Global/MCGSP	13/11.61			
	GP_{DGx} /$MCSP_{DGx}$	90/11.43	60/10.96	LD_{LDCx} /$MCBP_{LDCx}$	73/11.08	80/11.25		
6	GP_{DGx} /AP_{DGx}	30/9	70/9.9	LD_{LDCx}/ BP_{LDCx}	46/13.5	80/12.15	+26/12.16	0
	Local/MCP_{LCx}	30/11.25	70/11.02	Local/MCP_{LCx}	30/11.25	70/11.02		
	Global/MCGBP			Global/MCGSP	16/12.61	10/11.43		
	GP_{DGx} /$MCSP_{DGx}$	30/11.25	70/11.02	LD_{LDCx} /$MCBP_{LDCx}$	46/11.72	80/11.07		

Table 9. Case2-Load details of residential loads connected to respective LDCx with DR.

Int	LDC1									LDC2						
	$MCMGP_{LDC1}$ (MCP_{LDC1})	£		L_{11}* (P)	L_{12}* (P)	L_{13}* (P)	L_{14}* (P)	L_{15}* (P)	L_{16}* (P)	$MCMGP_{LDC2}$ (MCP_{LDC2})	£		L_{21}* (P)	L_{22}* (P)	L_{23}* (P)	L_{24}* (P)
1	70 (11.48)	0.7	C_{CLP} (MCP_{LDC1})	14 (11.48)	10.5 (11.48)	14 (11.48)	7 (11.48)	**10.5 (11.48)**	**14 (11.48)**	80 (11.25)	0.8	C_{CLP} (MCP_{LDC2})	**16 (11.25)**	**24 (11.25)**	20 (11.25)	20 (11.25)
			TL_{Lxy} (LCP_{Lxy})	12 (11.48)	9 (11.48)	12 (11.48)	6 (11.48)	**9 (11.48)**	**12 (11.48)**			TL_{Lxy} (LCP_{Lxy})	**16 (11.25)**	**24 (11.25)**	20 (11.25)	20 (11.25)
			GL(MCGSP/ MCGBP)									GL(MCGSP/ MCGBP)				
2	90 (11.18)	0.9	C_{CLP} (MCP_{LDC1})	18 (11.18)	13.5 (11.18)	18 (11.18)	9 (11.18)	**13.5 (11.18)**	**18 (11.18)**	70 (11.25)	0.7	C_{CLP} (MCP_{LDC2})	**14 (11.25)**	**21 (11.25)**	17.5 (11.25)	17.5 (11.25)
			TL_{Lxy} (LCP_{Lxy})	20 (11.19)	15 (11.19)	20 (11.19)	10 (11.19)	**12 (10.91)**	**16 (10.91)**			TL_{Lxy} (LCP_{Lxy})	**12 (11.25)**	**18 (11.25)**	20 (11.25)	20 (11.25)
			GL(MCGSP/ MCGBP)	+2 (11.26)	+1.5 (11.26)	+2 (11.26)	+1 (11.26)	**-1.5 (9.01)**	**-2 (9.01)**			GL(MCGSP/ MCGBP)	**-2 (11.25)**	**-3 (11.25)**	+2.5 (11.25)	+2.5 (11.25)
3	90 (11.18)	0.9	C_{CLP} (MCP_{LDC1})	18 (11.18)	13.5 (11.18)	18 (11.18)	9 (11.18)	**13.5 (11.18)**	**18 (11.18)**	80 (11.47)	0.8	C_{CLP} (MCP_{LDC2})	**16 (11.47)**	**24 (11.47)**	20 (11.47)	20 (11.47)
			TL_{Lxy} (LCP_{Lxy})	20 (11.19)	15 (11.19)	20 (11.19)	10 (11.19)	**12 (10.93)**	**16 (10.93)**			TL_{Lxy} (LCP_{Lxy})	**16 (11.47)**	**24 (11.47)**	15 (11.47)	15 (11.47)
			GL(MCGSP/ MCGBP)	+2 (11.26)	+1.5 (11.26)	+2 (11.26)	+1 (112)	**-1.5 (9.01)**	**-2 (9.01)**			GL(MCGSP/ MCGBP)				
4	80 (10.96)	0.8	C_{CLP} (MCP_{LDC1})	16 (10.96)	12 (10.56)	16 (10.96)	8 (10.96)	**12 (10.56)**	**16 (10.96)**	70 (11.03)	0.7	C_{CLP} (MCP_{LDC2})	**14 (11.03)**	**21 (11.03)**	17.5 (11.03)	20 (10.8)
			TL_{Lxy} (LCP_{Lxy})	20 (11.06)	15 (11.06)	20 (11.06)	10 (11.06)	**12 (10.96)**	**16 (10.96)**			TL_{Lxy} (LCP_{Lxy})	**12 (10.71)**	**18 (10.71)**	25 (11.15)	25 (11.15)
			GL(MCGSP/ MCGBP)	+4 (11.47)	+3 (11.47)	+4 (11.47)	+2 (11.47)					GL(MCGSP/ MCGBP)	**-2 (9.14)**	**-3 (9.14)**	+7.5 (11.43)	+7.55 (11.43)
5	60 (10.96)	0.6	C_{CLP} (MCP_{LDC1})	12 (10.96)	9 (10.96)	12 (10.96)	6 (10.96)	**9 (10.96)**	**12 (10.96)**	90 (11.48)	0.9	C_{CLP} (MCP_{LDC2})	**18 (11.48)**	**27 (11.48)**	22.5 (11.48)	22.5 (11.48)
			TL_{Lxy} (LCP_{Lxy})	16 (11.12)	12 (11.12)	16 (11.12)	8 (11.12)	**9 (10.96)**	**12 (10.96)**			TL_{Lxy} (LCP_{Lxy})	**16 (11.25)**	**24 (11.25)**	20 (11.25)	20 (11.25)
			GL(MCGSP/ MCGBP)	+4 (11.61)	+3 (11.61)	+4 (11.61)	+2 (11.61)					GL(MCGSP/ MCGBP)				
6	30 (11.25)	0.3	C_{CLP} (MCP_{LDC1})	6 (11.25)	4.5 (11.25)	6 (11.25)	3 (11.25)	**4.5 (11.25)**	**6 (11.25)**	70 (11.02)	0.7	C_{CLP} (MCP_{LDC2})	**14 (11.02)**	**21 (11.02)**	17.5 (11.02)	17.5 (11.02)
			TL_{Lxy} (LCP_{Lxy})	12 (11.93)	9 (11.93)	12 (11.93)	6 (11.93)	**3 (10.67)**	**12 (10.67)**			TL_{Lxy} (LCP_{Lxy})	**12 (10.70)**	**18 (10.70)**	25 (11.14)	25 (11.14)
			GL(MCGSP/ MCGBP)	+6 (12.61)	+4.5 (12.61)	+6 (12.61)	+3 (12.61)	**-1.5 (10.09)**	**-2 (10.09)**			GL(MCGSP/ MCGBP)	**-2 (9.14)**	**-3 (9.14)**	+7.5 (11.43)	+7.5 (11.43)

Case 1 is 11.16 INR/kWh and Case 2 is 11.41 INR/kWh. Clearly the selling prices are increased.

Similarly, in Fig.8, during the time interval 3 (for the buyer), BP_{LDC1} of LDC1 before the execution of DR program in both the cases is 11.25 INR/kWh and after the execution of DR program is 11.56 INR/kWh. $MCBP_{LDC1}$ before the execution of DR program in Case 1 is 11.25 INR/kWh, and in Case 2 it is 11.182 INR/kWh. Again, it is clear that the buying price has decreased. Thus, the proposed trading mechanism is beneficial to both the stake holders.

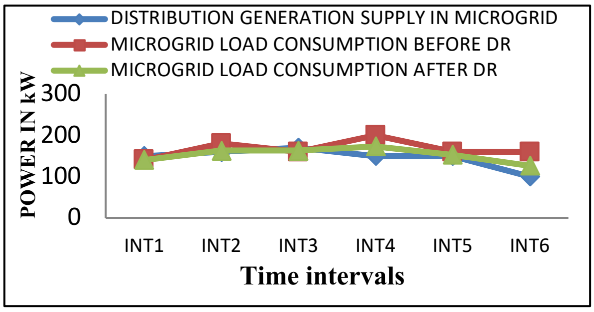

Fig. 4. Supply and Demand curves.

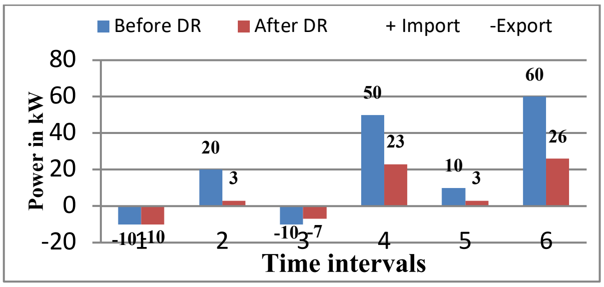

Fig. 5. Microgrid Import/Export power before and after DR.

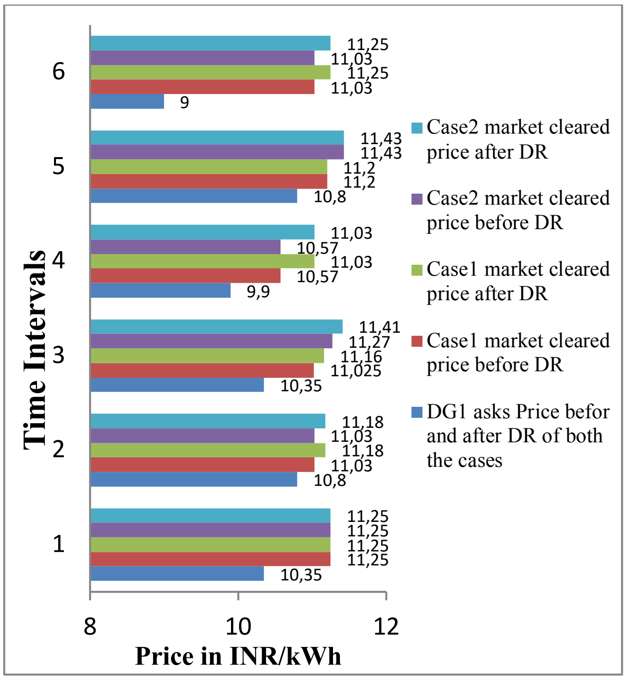

Fig. 6. DG1, ask and market cleared prices before and after DR.

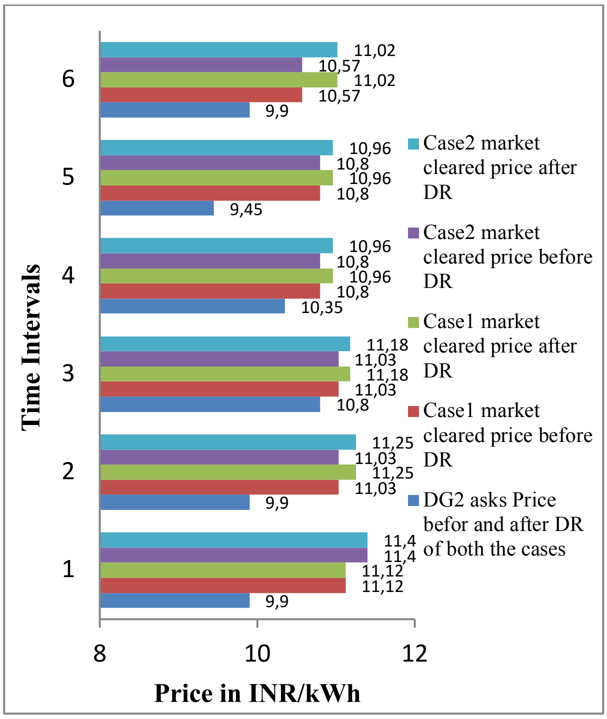

Fig. 7. DG2, ask and market cleared prices before and after DR in Case1 and Case2.

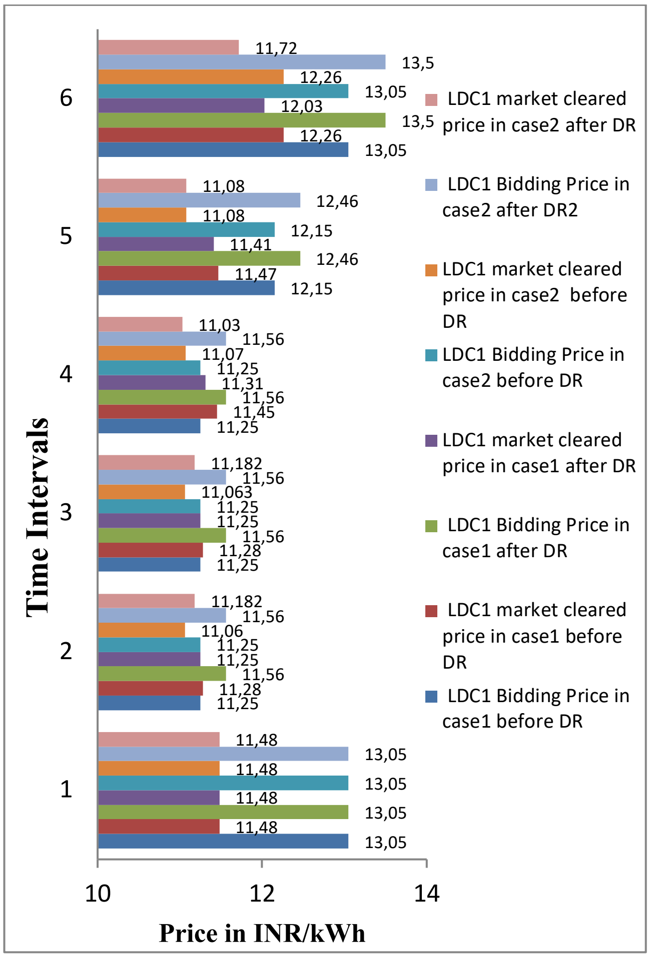

Fig. 8. LDC1, bid and market cleared prices before and after DR.

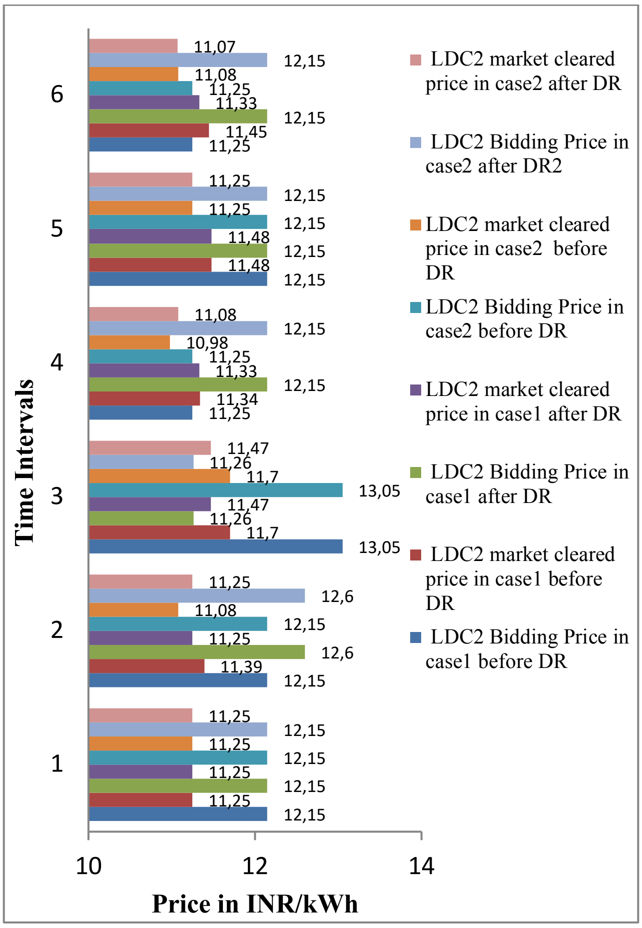

Fig. 9: LDC2, bid and market cleared prices before and after DR.

Fig. 10(a) and 10(b) shows the comparisons of LCP in both the cases, before and after the execution of DR for the customers L_{11} (DR non participating customer) and L_{16} (DR participating customer). It is clear that, the customers participating in DR options are benefited by the proposed incentive policy, and in addition, there an effective variation in LCP of non DR participating customer. (e.g.: during the time interval 2, LCP_{L11} and LCP_{L16} before execution of DR program in Case 1 is 11.28 INR/kWh and in Case 2 is 11.06 INR/kWh, and after execution of DR program, LCP_{L11} in Case 1 is 11.41 INR/kWh and Case 2 is 11.19 INR/kWh, and LCP_{L16} in Case 1 is 10.9 INR/kWh and Case 2 is 10.9 INR/kWh.)

Fig.11 shows the comparison of $MIAP_{TI}$, before and after the execution of DR in both the cases. It is observed that, DR participation of some of the LA_{XY} and the proposed second energy trade mechanism effectively decreases the $MIAP_{TI}$. (e.g.: during the time interval 3 in Fig.11,$MIAP_{TI}$ before execution of DR in Case 1 is 180 INR/time interval and Case 2 is 54.4 INR/ time interval, and after execution of DR in Case 1 is 52INR / time interval and Case 2 is 2.88 INR/ time interval). Thus the proposed second energy trade mechanism increases the profit margin of the stake holders.

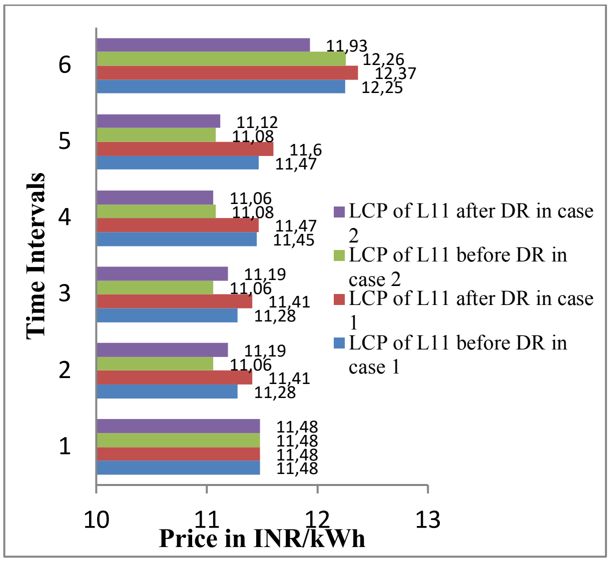

Fig. 10(a). LCP of L_{11}

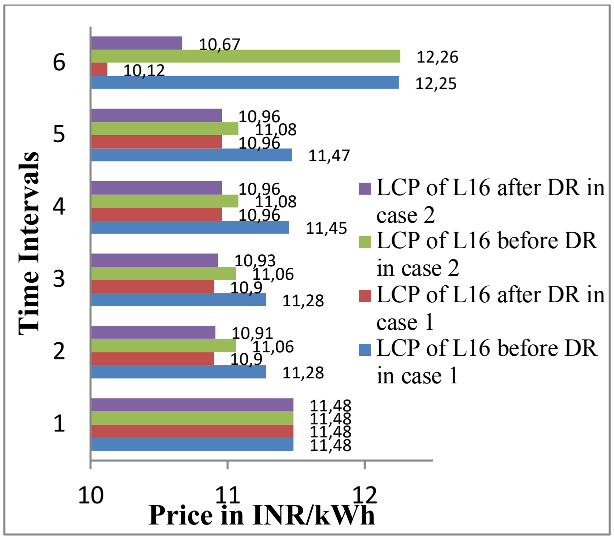

Fig. 10(b). LCP of L_{16}

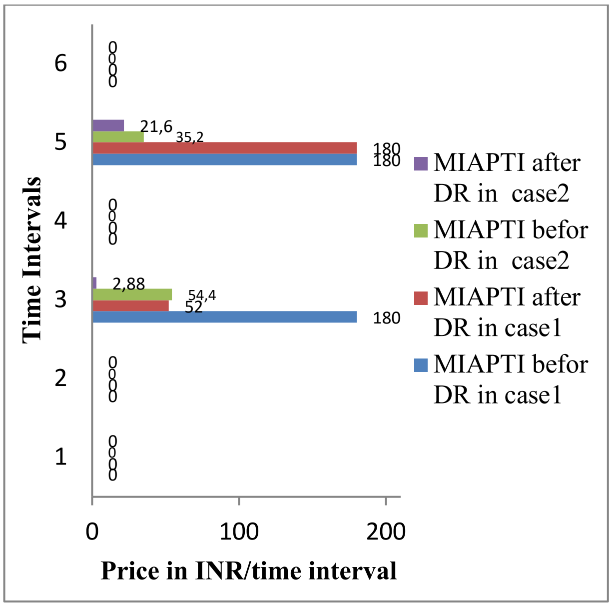

Fig. 11. Comparison of $MIAP_{TI}$ before and after DR.

6. Conclusions

The microgrids are becoming more complex and active systems. Although there are several advantages of this development, there exist diverse set of challenging issues as well. The management of the DERs with a competitive trading mechanism is one among these challenges.

In this paper, a MEMF for trading and managing the power in a grid-tied microgrid with DR is presented. The proposed MEMF and energy trade mechanisms to co-ordinate local and global market auctions are validated using a test distribution system. The effect of DR participation on bidding and market clearing prices of DGs and LDCs from the proposed novel linear bidding algorithm and energy trade mechanisms are presented. The simulation results indicate the effectiveness of the proposed new trading mechanism in the global market, as it enhances the profit margin of stake holders compared to a similar trading mechanism used in [14,25]. The MEMF with DR is also very effective in mitigating/reducing the overall peak demand and dependency on the grid. It is also found that the customers participating in DR were benefited by the proposed incentive policy and effective variation in LCP of non DR participating customer due to DR participation of some of the customers in the DN. The main outcomes of this work can be summarized as follows:

1. A linear bidding algorithm is introduced to decide the quote prices of stake holders for day-ahead market auction.
2. A new trade mechanism is designed for global market auction based on supply demand mismatch of microgrid and limiting prices of the grid in order to increase the profit margin of stake holders.
3. A novel load distribution management mechanism is introduced in LDCs by introducing a factor (DLCF) and clearing power for customer (C_{CLP}) in the local market auction.
4. The control to exercise the DR options is given to the customers rather than the aggregator.
5. A novel 'give-up' policy is introduced for the customers and the generally used incentive policy is also modified to yield more benefits to the customers when they are participating in DR program.

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