A Smart Distribution Transformer Management with Multi-Agent Technologies

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Abstract-- **The objective of this paper is to demonstrate an approach to perform distribution transformer management with multi-agent technologies. With the proposed approach, the distribution transformer's loading level is kept below a certain value by dynamically allocating the transformer's demand limit (DL) among the homes served by the transformer during a demand response event. The DL assignment takes into account, for each home, its load profile (kW), electrical panel size (A), expected instantaneous demand (kW), and homeowner's preferences. The proposed set of algorithms is developed in a multi-agent system (MAS). In this paper, the MAS is designed, developed and implemented in JAVA Agent Development Framework (JADE). A distribution network is simulated in MATLAB/Simulink integrated with the developed stand-alone HEM software. These platforms are linked together via MACSimJX middleware and TCP/IP communications.**

Index Terms—**Demand response, smart transformer, multi-agent system, JADE, and home energy management system**

I. Introduction

Conventionally, deficiency of bulked power supply systems resulting from unanticipated contingencies such as loss of generators or loss of transmission lines imposes forced outages to a large number of electricity users. This is because existing load shedding schemes typically target the transmission or sub-transmission level to shed blocks of customers [1]. Recently, demand response (DR) has been introduced by many Independent System Operators (ISO's) across the U.S. [2, 3, 4, 5] to manage end-use loads and help mitigate impacts of large-scale load shedding.

There is the number of previous work that proposes different approaches to accommodate DR implementation in a distribution network [6, 7, 8, 9]. Based on these approaches, end-use customers (residential and commercial buildings) are modeled as lumped loads in which characteristics of individual appliances (e.g., HVAC, water heater, clothes dryer) are not considered or observed.

This paper proposes a set of algorithms that allows for DR implementation at a distribution transformer level. The main objective is to reduce the total instantaneous power at a transformer during an emergency condition. This can be accomplished by dynamically allocating a demand limit (DL) to its connected homes, taking into consideration, for each home, its load profile, electrical panel size, expected instantaneous demand, and homeowner preferences. The proposed set of algorithms is implemented in a multi-agent system (MAS) and a home energy management system (HEM). MAS consists of multiple distributed intelligent agents, which is designed, developed and implemented in JAVA Agent Development Framework (JADE) [10]. The HEM system, previously developed in [11], is responsible for monitoring and scheduling the operation of in-home appliances according to a specified set of requirements. A distribution network is simulated in the MATLAB/Simulink environment. The simulated distribution network is linked with the MAS via MACSimJX middleware [12]. The MAS and the HEM communicates through TCP/IP connections.

This paper is organized as follows. The proposed DR algorithms for a smart distribution transformer management are discussed in Section II. The MAS architecture and its design are described in Section III. Integration of the developed MAS with the simulated distribution network and the HEM is explained in Section IV.

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II. DR Algorithms for a Smart Distribution Transformer Management

The overall objective of the proposed algorithms is to keep the total instantaneous demand at a distribution transformer below a certain demand limit (DL) level during a DR event. A DR event is defined as a period during which there is the need for a utility to request for a demand reduction from end-use customers – especially when there is a power supply shortfall in the system. This can be carried out by a control center sending DL requests (kW) to selected substations, which subsequently is transferred to DL at selected distribution transformers. In this paper, it is assumed that the DL at a distribution transformer is given during an emergency condition. The proposed set of algorithms will make an effort to manage the transformer's load below this limit. The proposed approach must be implemented at the transformer level, the home level and the appliance level, as follows:

A. Algorithms at a Distribution Transformer Level

Taking into account power system security and the merit of decentralized control system of an agent-based system, a distribution transformer operating state can be assessed on-line based on its operating constraints (equality/inequality). A distribution transformer's goals (objectives) and its constraints (considering mainly real power) are as follows:

Goals:

1. To minimize the probability of an overly increased demand after a DR event ends due to a low DL level as pointed out in [11].

2. To minimize the time used to return to the transformer's secure operating conditions.

Equality constraints:

$$P_{TR} = P_{coincidence-homes} \quad (1)$$

Inequality constraints:

$$P_{TR} \leq TRA_{loading_{cap}} \quad (2)$$

$$P_{TR} \leq DL_{TR} \quad (3)$$

Where,

P_{TR} : instantaneous real power at a transformer (kW)

$P_{coincidence-homes}$: aggregated coincidence power of homes (kW)

$TRA_{loading_{cap}}$: loading capability of a transformer (kW)

DL_{TR} : demand limit given by a distribution substation (kW)

In this paper, we consider two operating states of a distribution transformer: normal and emergency. The normal state corresponds to a normal system operating condition before a DR event occurs (no constraint is violated). The emergency state corresponds to the condition during an occurrence of a DR event (if any inequality constraint is violated). The overall algorithm for a distribution transformer management, which will be discussed in details in Sections III and IV, is shown in Fig. 1.

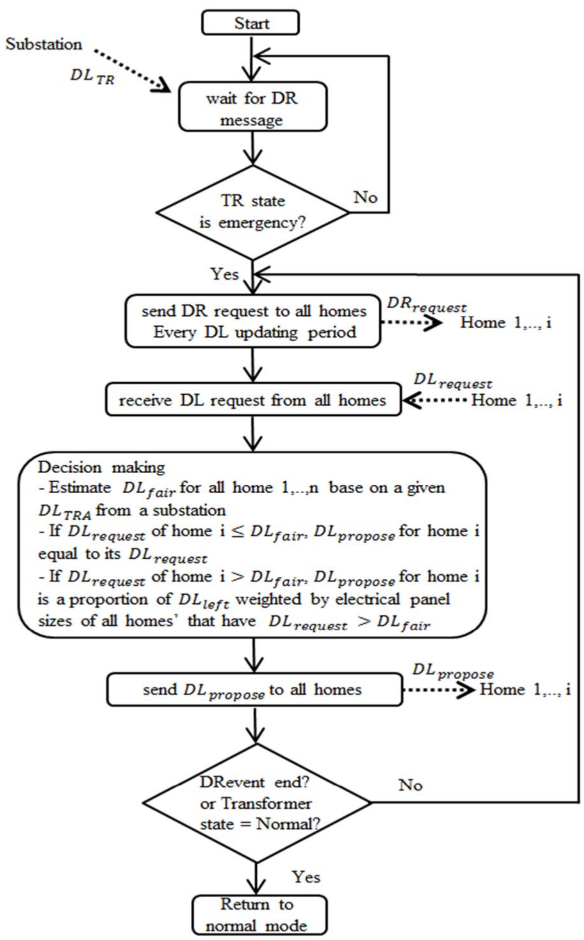

Fig. 1. Overall algorithm for a smart transformer management.

B. Algorithms at a Home Level

A home can be considered as single entity acting in response to its corresponding distribution transformer. During either a normal or an emergency operating state, the proposed algorithm tries to achieve home's objectives subjected to the system and its own constraints as follows.

Goals:

1. To secure critical loads as well as minimize customer's comfort level violation.

2. To minimize appliances' operating times (idle time plus run time).

Equality constraints:

$$P_{home} = P_{TR-home} \quad (4)$$

Inequality constraints:

$$P_{home} \leq DL_{home} \quad (5)$$

Where,

P_{home} : instantaneous real power at home (kW)

$P_{TR-home}$: home instantaneous power seen at transformer (kW)

DL_{home} : demand limit given from a distribution transformer (kW)

The overall algorithm of a home in response to the transformer demand management algorithm, which will be discussed in detail in Sections III and IV, is shown in Fig.2.

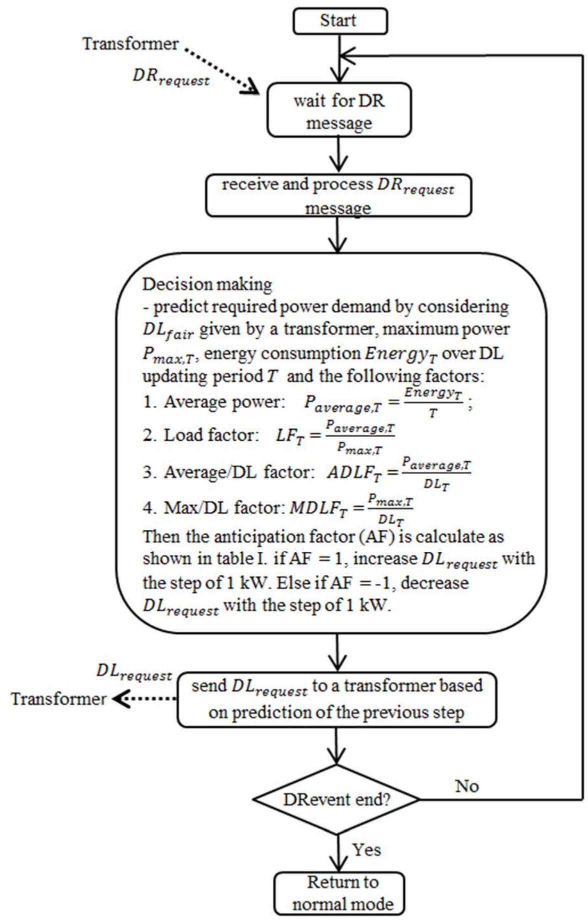

Fig. 2. Overall algorithm for a home.

For each decision making period (e.g., 10 minutes, 15 minutes, etc.), the following key factors must be determined: the load factor (LF), the ratio of average load to demand limit factor (ADLF), and the ratio of maximum load to demand limit factor (MDLF). The anticipation factor (AF) is evaluated by comparing these factors with a constant ε that represents a decision boundary. This constant will influence the decision for each home agent to request a higher demand limit (AF=1) during the next time step, or reduce its demand limit (AF=-1) during the next time step. Due to the inherited nature of average power, maximum power, and DL, there are four possible cases of the AF prediction, which is summarized in Table I.

TABLE I
ANTICIPATION FACTOR PREDICTION (ε is decision boundary)

Factor	Case I	Case II	Case III	Case IV
LF	> ε	> ε	≤ ε	≤ ε
ADLF	> ε	≤ ε	≤ ε	≤ ε
MDLF	> ε	≤ ε	> ε	≤ ε
AF	1	-1	-1	-1

C. Algorithms for Home Energy Management (Appliance)

HEM algorithms previously developed in [11] are used to guarantee that the total household instantaneous demand is kept below a specified DL level (kW) during a specified duration (minute). By setting critical loads (i.e., plug loads) to have the highest priority, the HEM accomplishes this task by communicating and regulating energy-intensive appliances: water heater (WH), air conditioner (AC), clothes dryer (CD), and electric vehicle (EV) taking into account customer preference settings. An example of a preference setting by a homeowner is given in table II.

TABLE II
EXAMPLE OF LOAD PRIORITY AND PREFERENCE SETTING

Appli-ance	Load priority	Homeowner preference
WH	1	Water temperature 110 – 120 ˚F
AC	2	Room temperature 76(±2) ˚F
CD	3	Finish job by midnight; max OFF/min ON time: 30 min
EV	4	Fully charged by 8 AM; min charge time: 30 min

III. MAS ARCHITECTURE AND DESIGN

In this section, the proposed MAS architecture, agent's behaviors design, agents' knowledge modeling and agent communication and negotiation process during a DR event are discussed in details.

A. Agent Architecture

The proposed MAS comprises two types of agents. Their roles and responsibilities are defined as follows.

1. *Transformer Agent* (*TRA*): A *TRA* resides at a transformer acting as a coordinator between a distribution substation control center and its associated home agents (*HAs*). The *TRA* is designed to be able to monitor and assess its own operating state as well as acquiring knowledge from other *HAs* and its environment. Integrated with the algorithms discussed in Section II.A, during a normal state, the *TRA* constantly assesses whether or not its constraints are within acceptable ranges. If the operating state of the transformer is in an emergency state indicating a DR event, the *TRA* attempts to reduce it electricity demand by automatically working, communicating, and collaborating with its connected *HAs* based on the algorithm given in Section II.A. In addition to achieving the system's goals, the *TRA* also attempts to achieve its own goals as stated earlier.

2. *Home Agent* (*HA*): A *HA* resides at each home, acting as a coordinator between the *TRA* and an HEM. It provides a home interface with the *TRA* via a gateway (e.g. a smart meter or a dedicated electronic device), as well as an interface with the HEM using TCP/IP communications. The *HA* receives two types of data: (a) a DR event signal from the *TRA* specifying a DL amount (kW) with an updating period, i.e., the period which a DL level remains the same in minutes and (b) a data from HEM including instantaneous power and energy consumption profiles. As mentioned in Section II.B, the *HA* is designed to work in collaboration with an HEM to ensure that the total household electricity demand will be kept below a given DL assigned by the *TRA* during a transformer*'s* emergency state. In addition to achieving the system goals, *HA* also strives to reach its own goals.

The proposed MAS architecture is depicted in Fig.3.

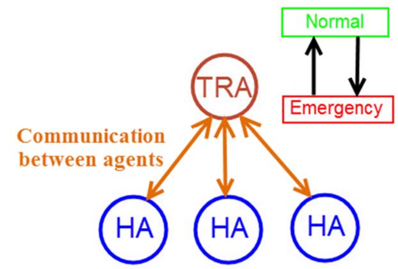

Fig. 3. The proposed MAS architecture.

B. Agent Behavior Design

Agents' abilities are defined by their behaviors which determine how an agent should react to other agents and its environment in pursuit of the overall system and its own goals. Agents' behavior design based on the transformer and home algorithms in Sections II.A and II.B are summarized in Table III.

TABLE III
AGENT BEHAVIORS

Agent	Behaviors	Description
TRA	Filter	Exchange messages between *TRA* and MATLAB/ Simulink environment data
	DrResponder	Wait for DR event signal from a distribution substation control center, if DR event signal is true, *TRA* will quickly assess its operating state. If the state is normal (current instantaneous demand at a transformer lower that a given DL), *TRA* will do nothing except keep estimating its state for the next DL updating period. If the state is emergency (current instantaneous demand at a transformer higher that a given DL), *TRA* will activate a DrActivator behavior.
	DrActivator	Notify *HAs* about a DR event by sending a 'Request' message to all HAs. Then wait for an 'Inform-done' message from all HAs indicating that *TRA* has already done its DR corrective control.
	OfferRequest Server	Wait for a 'Call-For-Proposal (CFP)' message from *HAs*. Then, send a 'Propose' message specifying DL back to each *HA*. If $DL_{request}$ of a HA is less than or equal a DL_{fair} among all homes, send $DL_{propose} = DL_{request}$. Otherwise, $DL_{propose}$ for a *HA* is weight by electrical panel sizes of all homes that $DL_{propose} > DL_{fair}$.
	MatchingSer ver	Wait for an 'Accept Proposal' message indicating and ensuring that *HAs* receive the 'Propose' message sent earlier and ready to perform a DR corrective action.
HA	Filter	Exchange messages among *HA*, MATLAB/ Simulink environment, and HEM.
	DrResponder	Wait for DR event signal from a *TRA*, if DR event signal is true, *HA* will readily send 'Agree' message back to *TRA* signaling that it is preparing a 'CFP' message to request for a DL for the next DL updating period. After that, it activates a RequestPerformer behavior. Then, After the Filter behavior done passing the DL to a HEM, this behavior send an 'Inform-done' message back to *TRA* indicating *HA* has already done its DR corrective control.
	LoadPredicto r	Calculate all of the required factors (LF, ADLF, MDLF) during time period T. Then, predict a DL request by evaluating AF to satisfy the need of a *HA* corresponding to its goals. Regarding table I, if AF=1, increase $DL_{request}$ with step = 1kW. Else if AF=-1, decrease $DL_{request}$ with step = 1kW.
	RequestPerfo rmer	Send a 'CFP' message to request for a DL for each DL updating period based on the anticipated electricity demand required to satisfy its need obtaining from the LoadPredictor behavior. Then, it waits for a 'Propose' message from TRA stipulating what is the DL level for this HA. Since, a TRA is still in emergency condition, HA will send back an 'Accept Proposal' message. Finally, wait for a confirmation 'Inform-done' message from TRA before sending out DL level to HEM via a Filter behavior.

C. Agent Knowledge Modeling

Different types of agents need different sets of data to process and transfer to their behaviors. Hence, it is imperative to model suitable knowledge specifically for each type of agents and its corresponding behaviors. Table IV summarizes agents' knowledge (attributes) that TRA and HA inherit or need to acquire by exchanging messages with one another as well as its external environment.

TABLE IV
AGENT'S ATTRIBUTES

Attributes	Value	Attribute	Value
TRA			
- ID	String	- DL	Double (kW)
- AID	AID	- DL fair	Double (kW)
- Rating	Double(kVA)	- DL updating time	Integer (min)
- Voltage ratio	Double	- Connected homes	Integer
- Configuration	(A,B,C-N)	- HA IDs	ID*
- Priority	Integer	- HA AIDs	AID*
- Loading capability	Double (kW)	- HA status	Boolean*
- Operating state	String	- HA elec. panel size	Integer(A)*
- Service type	String	- HA priority	Integer*
- DR event	Boolean	- HA DL request	Double(kW)*
- Demand (P)	Double (kW)		
HA			
- ID	String	- Load factor (LF)	Double
- AID	AID	- Avg/DL factor (ADLF)	Double
- Elec. panel size	Double(A)	- Max/DL factor(MDLF)	Double
- Voltage rating	Double (V)	- HA AF	Integer[-1,0,1]
- Status	Boolean	- DL request	Double(kW)
- Priority	Integer	- TRA IDs	ID
- DR event	Boolean	- TRA AIDs	AID
- Demand (P)	Double (kW)	- TRA status	Boolean
- Energy (E)	Double (kWh)	- TRA state	String
- Max. demand (P_{max})	Double (kW)	- DL	Double (kW)
- Avg. demand (P_{avg})	Double (kW)	- DL updating time	Integer (min)
- Load factor (LF)	Double		

Note: * indicates an array of that data type.

D. Agents' Communication and Negotiation Processes during a DR Event

After a problem(s) is assigned to an agent, if it cannot solve the problem using its own resources, knowledge or expertise, it will break down the problem into several small sub-problems and try to find another agent(s) having abilities or resources to cope with the problem. In this paper, if a *TRA* is in an emergency condition, it needs to commit to reduce its demand. The *TRA* then searches for lower layer agents which are capable of responding to a DR event. Working together, the system's goals can be achieved by communication and negotiation processes of a *TRA* and *HAs*. For a smart transformer management application, there are two main communication protocols used by a *TRA* and a *HA*: FIPA Request Interaction Protocol and FIPA Contract Net interaction protocol (FIPA stands for Foundation for Intelligent Physical Agents [13]).

The interactions during a DR event between entities in the proposed MAS can be represented using the sequence diagram depicted in Fig. 4. Communication and negotiation process corresponds to the designed behaviors can be described according to the following steps.

Step 1: During a normal condition, Filter behaviors of *TRA* and *HAs* (See all behaviors defined in Table III) keep updating their knowledge by exchanging 'inform' messages with a simulated circuit (MATLAB/Simulink) and HEMs.

Step 2: The *TRA* receives a 'request' message specifying a DL from a substation. Then, it assesses its operating state whether or not its state move from normal to emergency. If its state has changed to emergency, the DrResponder behavior sends 'agree' message back to the substation and activate the DrActivator accordingly.

Step 3: After being activated, the DrActivator sends 'request' message to *HA* notifying the DR event.

Step 4: The DrResponder behavior of a *HA* responds to the message by sending 'agree' message to *TRA*.

Step 5: The RequestPerformer behavior of a *HA* sends a 'cfp' message to the *TRA* with its desired DL resulting from running the LoadPredictor behavior in accordance with the *HA* algorithm discussed in Section II.B.

Step 6: The OfferRequestServer behavior receives the 'cfp' messages. Then, it proceeds and deduces the requested DL of all *HAs* based on the *TRA* algorithm discussed in Section II.A before sending 'propose' messages back to *HAs*.

Step 7: *HA* acknowledges the received message and send 'accept proposal' message back to the *TRA*.

Step 8: The *TRA* MatchingServer Behavior confirms the given DL by sending an 'inform: done' message to its associated *HAs*.

Step 9: Finally, the *HA* Filter behavior passes the assigned DL to its corresponding HEM which will be ensure that the total household instantaneous demand will not exceed the DL level according to the HEM algorithm discussed in Section II.C.

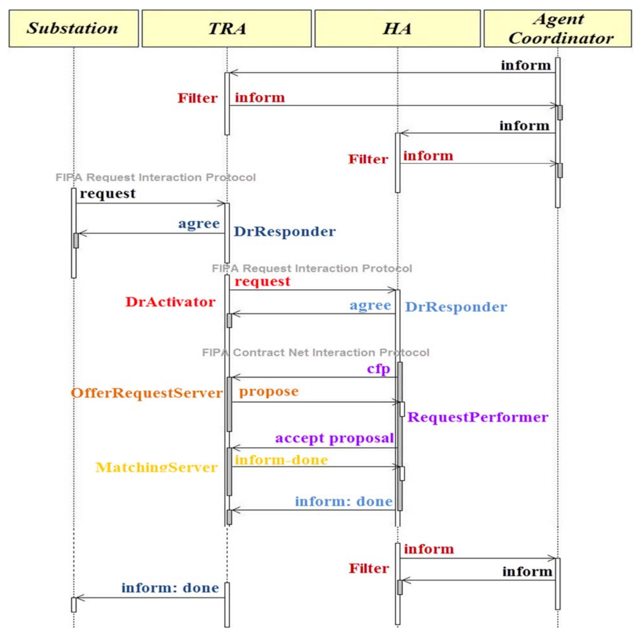

Fig. 4. Sequence diagram of the proposed MAS.

IV. Integration and Implementation of the Developed Multi-Agent System

A. Integration of MAS with MATLAB/Simulink and HEM

In the simulated environment, the MAS (developed in JADE framework) and the distribution network (modeled and simulated in the MATLAB/Simulink environment) reside in the same workstation and are connected together using a middleware called MACSimJX. MACSimJX allows the distribution network modeled in MATLAB to be controlled by agents running in an external program. The HEM (stand-alone software developed in [11]) is linked with the MAS and the distribution network via TCP/IP communications.

B. Case Study Description

The simulated circuit as shown in Fig. 5 consists of one 25kVA distribution transformer serving three homes. Each home has an HEM. As shown, the MAS comprises a *TRA* and three *HAs*. This circuit is used to demonstrate how the proposed MAS can perform distribution transformer management during a DR event based on the algorithms discussed in Section II. This case study assumes that a DR event has occurred, and the transformer receives a DR event signal with a 15 kW DL for a one hour period between 17:10 and 18:10. In this simulation, home parameters, appliance ratings and customer preferences, as well as other related assumptions, are given in Tables V and VI respectively.

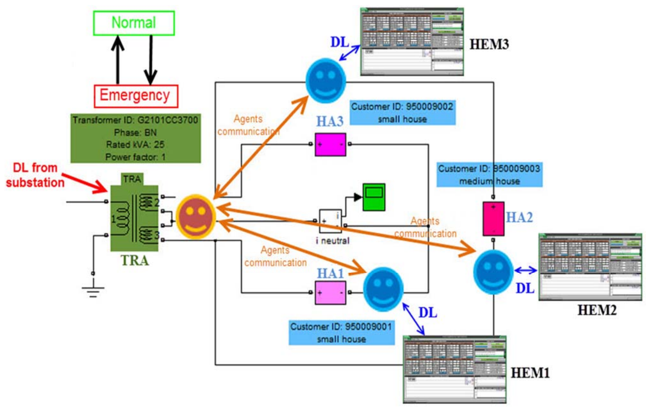

Fig. 5. Case study: one transformer and three connected homes.

TABLE V
HOME ATTRIBUTES AND CUSTOMER PREFERENCE SETTINGS

	Home 1 (HA1,HEM1)	Home 2 (HA2,HEM2)	Home 3 (HA3,HEM3)
Home parameters:			
- ID	950009001	950009002	950009003
- size	small (1,500 ft^2)	medium (2,500 ft^2)	small (1,500 ft^2)
- Elec. panel size	125 A	225 A	125 A
- Voltage rating	120/240 V	120/240 V	120/240 V
- Status	true	True	true
- season	summer	summer	summer
- weather	sunny	Sunny	sunny
Appliances ratings and customer preference setting:			
1. WH	3.8 kW, p=2, 120 $\pm$ 10 F°	4.5 kW, p=2, 120 $\pm$ 10 F°	off
2. AC	1.92 kW, p=1, 76 $\pm$ 2 F°	2.6 kW, p=1, 76 $\pm$ 2 F°	1.92 kW, p=1, 80 $\pm$ 2 F°
3. CD	2.88 kW, p=3, start 17:00	4.9 kW, p=3, start 16:50	off
4. EV	-	3.3 kW, p=4 start 16:30	-
Assumptions:			
DR event	17:10 – 18:10	17:10 – 18:10	17:10 –18:10
Residents (N)	4 people	3 people	2 people
N during a DR event	2 people	3 people	0 people
ε (decision boundary)	0.5	0.5	0.5

TABLE VI
TRANSFORMER ATTRIBUTES

Attribute	Value	Attribute	Value
Transformer			
- ID	G2101CC3700	- DR event	true at 17:10
- Rating	25 kVA	- DL	15 kW
- Voltage ratio	7.2kV/120/240V	- DL updating time	10 min
- Configuration	BN	- Demand (P) at17:10	> 15kW
- Loading capability	> 25 kW	- HA IDs	950009001, 950009002, 950009003
- Operating state	Normal before 17:10	- DL updating period	10 min

C. Simulation Results and Discussions

Simulation results (Fig. 6) compare the total instantaneous power of the 25kVA distribution transformer of interest and the instantaneous power of homes 1, 2 and 3 with and without demand response (DR). The simulation starts at 17:00. The chronology of events is described below:

After the DL of 15kW is imposed at the transformer, the TRA calculates the fair demand limit values (DL_{fair}) for three homes. These are 3.95 kW for homes 1 and 3, and 7.1 kW for home 2. These numbers are derived based on the electrical panel size of each home (Table V).

At 17:10, the instantaneous power seen at the transformer (18.53 kW) is higher than the assigned DL (15 kW). The operating state of the transformer changes from normal to emergency. Then, the *TRA* proactively reacts to this condition by sending DR requests to its corresponding *HAs* to reduce its total demand. The allocated DL to *HA1*, *HA2* and *HA3* are 5, 7.5, and 2.5 kW respectively. After being allocated DL, *HA*s work with HEMs that automatically decide which appliances should be turned on or off based on preset homeowners' preferences. Notice that the total instantaneous demand of the transformer is reduced to 14 kW at 17:11. This is one minute after the TRA receives the DR event signal. This 1-minute delay is accounted for the communication and decision making process of HEM for household appliance control [11].

In this study, the DL updating period is set to every 10 minutes. At the first DL updating period (17:20), *HA3* predict that its demand in the next period will not increase (AF = -1). Since it needs to make sure that its critical loads are secured, *HA3* requests for the same DL level at 2.5 kW. *HA1* and *HA2* realize that the given DL might not meet their electricity demand for the next period (AF=1), they asked for more DL from the *TRA*. After the *TRA* gather requests from all *HAs*, it allocates DL according to the algorithm discussed in Section II. In this case, *HA3* asks for 2.5 kW which is less than DL_{fair} at 3.95 kW, the *TRA* proposes the same requested DL to *HA3*. On the other hand, *HA1* and *HA2* ask for DL more than their DL_{fair} (3.95 kW for *HA1* and 7.1 kW for *HA2*), the *TRA* then allocates the weighted DL to each of them. These are 4.5 kW for *HA1* and 8 kW for *HA2*.

In the next updating periods (17:30 and 17:40 PM), *HA3* has relatively lower demand so that its AF is still -1. The TRA then assigns the requested DL at 2.5 kW to *HA3*. *HA1* and *HA2* receive their previous weighted DL levels at 4.5 kW and 8 kW, respectively.

At 17:50 PM, AF of *HA3* is 1 due to its electricity demand during the previous period. Therefore, *HA3* requests for the higher DL which is 3.5kW (lower than 3.95 kW DL_{fair}). The *TRA* then agrees with the requested DL at 3.5kW. Again, despite of AF equal to -1 for HA1 and HA2, their DL requests still higher their DL_{fair}, the *TRA* then allocates the weighted DL to each of them which are 4.1 kW for *HA1* and 7.4 kW for *HA2*. These DL levels are retained until the end of the DR event at 18:10 PM.

During the DR period, it can be seen that the total instantaneous demand at the distribution transformer is kept below the assigned 15kW DL. Also, the electricity demand of each house is controlled below its allocated DL and some of their loads are shifted to the later time. The load compensation period for home 1 occurs after 18:00 when the total instantaneous demand with DR is higher than that without DR. That for home 2 occurs after 17:50. For home 3, since its power consumption is quite low (no people in the home), there is no impact of DR on its power consumption.

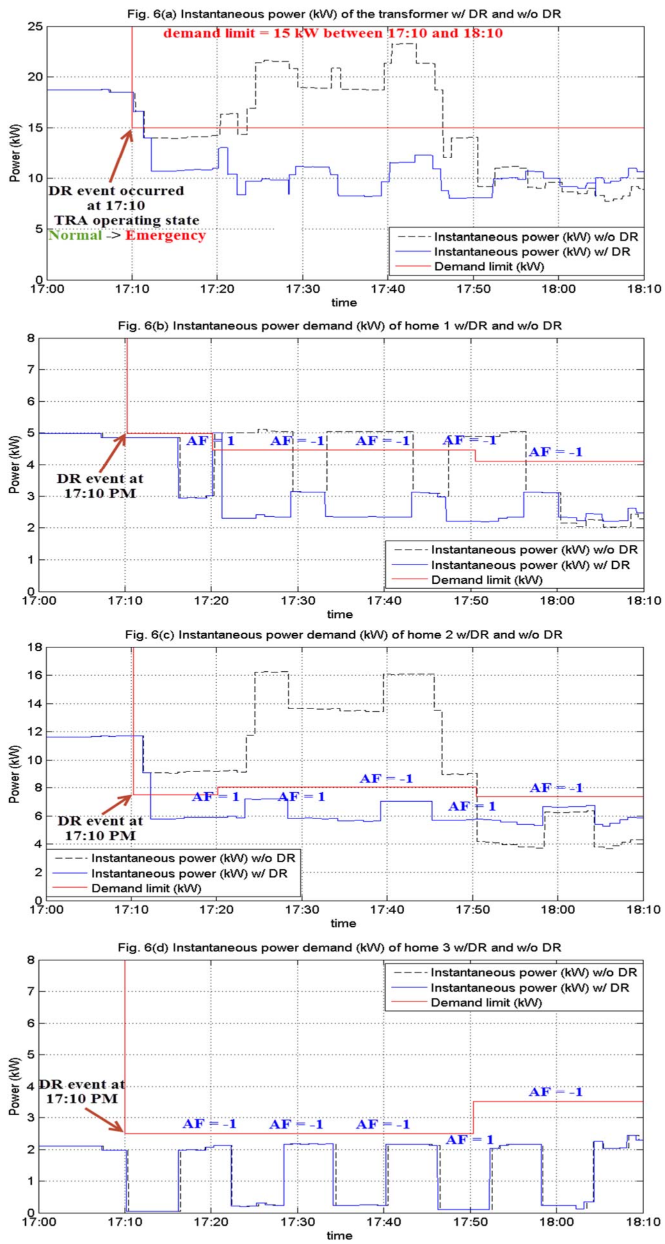

Fig. 6. Simulation results, showing instantaneous power of: (a) the distribution transformer; (b) home 1; (c) home 2; and (d) home 3.

V. Conclusions

This paper presents an approach to perform distribution transformer management using an agent-based technology. To successfully implement this approach, collaboration among cyber-layer intelligent agents resided at a distribution transformer, the home interface of each home it serves, as well as a home energy management system is needed. The proposed approach is validated by simulation studies, which showcase that the system goals were achieved during a DR event, i.e., the aggregated instantaneous demand has never exceeded the DL given by the substation. The DL is also reasonably allocated to each home. Overall, this paper demonstrates that the proposed MAS can perform DR implementation at a distribution transformer level, thus contributing to decreasing the likelihood of system stress conditions during an unanticipated power supply shortfall.

VI. References

[1] U. S. Department of Energy, “Benefits of demand response in electricity markets and recommendations for achieving them, a report to the United States congress pursuant to Section 1252 of the Energy Policy Act of 2005,” February, 2006.

[2] Langbein, P.L.; , "Demand response participation in PJM wholesale markets," *Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES* , vol., no., pp.1-3, 16-20 Jan. 2012

[3] Goodin, J.; , "California Independent System Operator demand response & proxy demand resources," *Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES* , vol., no., pp.1-3, 16-20 Jan. 2012

[4] Mukerji, R.; , "Demand response in the NYISO markets," *Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES* , vol., no., pp.1-2, 20-23 March 2011

[5] Wattles, P.; , "Load resources providing ancillary services in Electric Reliability Council of Texas (ERCOT)," *Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES* , vol., no., pp.1, 16-20 Jan. 2012

[6] Biabani, M.; Golkar, M.A.; Sajadi, A.; , "Operation of a multi-agent system for load management in smart power distribution system," *Environment and Electrical Engineering (EEEIC), 2012 11th International Conference on* , vol., no., pp.525-530, 18-25 May 2012

[7] Shengnan Shao; Pipattanasomporn, M.; Rahman, S.; , "Grid Integration of electric vehicles and demand response with customer choice," *Smart Grid, IEEE Transactions on* , vol.3, no.1, pp.543-550, March 2012

[8] Solanki, J.; Venkatesan, N.; Solanki, S.K.; , "Coordination of demand response and volt/var Control algorithm using multi agent system," *Transmission and Distribution Conference and Exposition (T&D), 2012 IEEE PES* , vol., no., pp.1-4, 7-10 May 2012

[9] Logenthiran, T.; Srinivasan, D.; , "Multi-agent system for managing a power distribution system with plug-in hybrid electrical vehicles in smart grid," *Innovative Smart Grid Technologies - India (ISGT India), 2011 IEEE PES* , vol., no., pp.346-351, 1-3 Dec. 2011

[10] JADE agent development toolkit [Online]. Available: http://jade.tilab.com.

[11] Pipattanasomporn, M.; Kuzlu, M.; Rahman, S.; , "An algorithm for Intelligent home energy management and demand response analysis," *Smart Grid, IEEE Transactions on* , vol.PP, no.99, pp.1, 0

[12] MACSIMJX [Online], Available: http://agentcontrol.co.uk/

[13] The Foundation for Intelligent Physical Agents: http://www.fipa.org/.

VII. Biographies

Warodom Khamphanchai received the M.Eng. degrees in Electric Power System Management, Energy Field of Study from Asian Institute of Technology (AIT), Thailand in 2011 and the B.Eng. degree from the Electrical Engineering Department, Faculty of Engineering, Chulalongkorn University, Thailand in 2009. He is currently pursuing his PhD degree in the Electrical and Computer Engineering Department, Virginia Tech. His research interests are artificial intelligence, power system optimization, renewable energy systems, distributed microgrids and multi-agent systems.

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Manisa Pipattanasomporn (SM’11 – IEEE) joined Virginia Tech's Department of Electrical and Computer Engineering as an assistant professor in 2006. She serves as one of the principal investigators (PIs) of multiple research grants from the U.S. National Science Foundation, the U.S. Department of Defense and the U.S. Department of Energy, on research topics related to smart grid, microgrid, energy efficiency, load control, renewable energy and electric vehicles. Her research interests include renewable energy systems, energy efficiency, distributed energy resources, and the smart grid.