Estimating Participation Abilities of Industrial Customers in Demand Response Programs: A Two-Level Decision-Making Tree Analysis

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***Abstract*— Industrial loads play an important role in the success of demand response programs (DRPs). However, these programs may lead to consumers' inconvenience which can overshadow their practicality. In response, this paper provides a two-level decision-making tree approach to effectively determine the participation abilities of different industrial processes in DRPs considering various features and abilities of these customers. The first level of this framework introduces some classifying variables by which a basic criterion is extracted to classify different industrial processes applying the analytic hierarchy process (AHP). A participation factor is then introduced in level II of the suggested decision tree to estimate the level of participation for different classes attained in Level I. Finally, a desirability coefficient is formulated, offering the system operators an efficient indicator to verify the attractiveness of different incentive-based programs in the viewpoint of industrial customers. Implementing the presented framework on industrial customers of a region in Iran, it is shown that applying this method lends the decision-makers a hand in practically and effectively introduce DRPs for industrial customers.**

***Index Terms*— Classification, incentive-based program, demand response, manufacturing line.**

NOMENCLATURE

A. Abbreviations

ASMP	Ancillary Services Market Program
AHP	Analytic Hierarchy Process
CMP	Capacity-Market Program
DB/BP	Demand Bidding/Buyback Program
DRP	Demand Response Program
EDRP	Emergency Demand Response Program
ES	Energy Storage
IBP	Incentive-based Demand Response Program
I/C Rate	Interruptible or Curtailable Rate Program
ILC	Industrial Load Classification
IM	Intermediate Material
ML	Manufacturing Line
NSP	Non-Stop Production
OG	On-Site Generation
CV	Classifying Variable
WH	Warehouse

B. Symbols

$AIG^{max,WH}$	Amount of max IM in the manufacturing process
$AIM^{used,WH}$	Amount of used IM in the manufacturing process
$AIM^{H,WH}$	Input amount of IM in ML for an hour
C^{OG}	Total power generation cost of OG
C_{ST}, C_P	Startup and power generation cost of OG
C_{PE}	Pollution emission cost of OG
C_{ES}	Cost of ES
C_{PS}	Cost of production stop
C_{WH}	Cost of storage IM in WH
PE	Price Elasticity of demand
D^{EIG}	Duration of entering IM
D^{MLG}	Duration of manufacturing low-energy goods
D_{ML}^{CS}	Duration between two consecutive stops of online-ML
D^{LLML}	Duration of launch low-energy ML
$\mathrm{D}_{\mathrm{LEM}}^{\mathrm{TCL}}$	Duration between two consecutive launches of Low-energy ML
DP_{LM}	Difference between the profit of low-energy goods and on-line manufacturing goods
ERT^{ES}	Energy retention time of ES
MN^{ES}	Max number of charging/discharging in a period
MN^{WH}	Max number of IM storage in a specified period
N^{MLS}	Number of ML stop
$N^{ST,OG}$	Startup number of OG
N_S^{OMG}	Number of stops of on-line-manufacturing goods
N_{LML}^{LP}	Number of launches of low-energy ML
$P^{max/min,OG}$	Lower & upper active power limit of OG
$P^{off/on,OG}$	Min up & Min downtime of OG
P^{ES}	Suggested power of ES
P^{CPT}	Consumption power per ton
PC^{HEG}	Power consumption of high-energy goods
PC^{LEG}	Power consumption of low-energy goods
PC^{GML}	Power consumption of goods in ML
PD	Preparation duration of LR
$P/E^{max,ES}$	Normal power and energy of ES
RD/RC^{ES}	Charging and discharging ramp of ES
RD/RU^{OG}	Ramp up and down limit of OG
ShD^{MLE}	Shutdown duration of ML Equipment
ShD^{GPL}	Shutdown duration of goods in ML
ShR^{MLE}	Shutdown rate of ML equipment
$ST^{min,OG}$	Minimum startup time for OG
$ST^{max,ES}$	Max startup time of ES
T^{CP}	Time period between two consecutive charges
Parti Coef	Participation coefficient

I. INTRODUCTION

DEMAND response is one potential tool that the system operators can implement to improve the system operation in a short time. These programs make a short-term impact on the generated power, delay the need for network reinforcement and increase the reliability and efficiency of energy systems. Demand response programs (DRPs) usually motivate the end-use customers to reduce their consumption when the market price is high or the network operation is at risk. Successful implementation of DRPs can lead to substantial benefits for customers through cost savings and incentivizing payments.

Several types of customers can participate in DRPs such as industrial, residential and commercial. This paper focuses on participants of industrial consumers in DRPs. While the implementation of DRPs may lead to consumers' inconvenience in the industrial sector, this sector is here accentuated for the following reasons:

- This sector has large, yet high-consumed number of consumers compared with the residential and commercial sectors. According to statistics from the International Energy Agency, this sector consumed 42% of the world's electrical energy in 2015. Therefore, a little change in energy usage of the industrial sector can have huge impacts on the delivered energy cost to the consumers and also on the security of the network operation.
- Industrial facilities already have been equipped with measurement, control and communication infrastructures, given the fact that the number of industrial consumers are far fewer than other sectors. Therefore, the data related to their usage can be transmitted more easily to dispatching centers. As a result, the system operator can conveniently manage the transmitted data, along with the condition of network operation and consumer requirements.
- Industries are able to provide a response in a large, fast and accurate way, which can create a fast power usage modification in a discrete manner. This can improve the system security under stressed and critical conditions.
- Some industries can reduce the consumption within a few minutes of being notified by the system operator while some others need a few hours to do so. In emergency conditions, some industries rely on process scheduling or backup equipment to maintain the electricity delivery for industrial processes, which can result in lower demand to be supplied by the ISO.

The above characteristics make industries and industrial loads more suitable for implementing demand response programs. To effectively apply these unique features in DRPs, some researchers have recently introduced several effective mechanisms [1-15]. However, most of them have ignored the practical barriers which could considerably affect the effectiveness and applicability of these programs. As an example, any changes in manufacturing processes of a plant will affect the other parts contributing to this process; this is due to the fact that manufacturing operation is a real-time process. This may result in unplanned outage and, thus production losses, mechanical failures of equipment and safety concerns.

As explained, some technical and financial barriers may affect the efficiency and applicability of DRPs. The authors in [16] have proposed a general method for demand response in industrial loads using a model architecture that characterizes the relationship between the equipment. However, this method has not quantitatively assessed the abilities of industries in providing DRPs. Moreover, this method is unable to consider the quantitative aspects of the network operational conditions. Authors in [17] have proposed a method for prioritizing the participation of commercial, residential and industrial consumers in emergency demand response program (EDRP) using the analytical hierarchy process (AHP) approach. However, the characteristics of different loads and the implementation of various demand response programs are ignored in this work. The authors in [18] have studied two classes of manufacturing processes, medium frequency induction furnace, and the electrolytic bath. Although this paper quantifies the amount of power reduction as a result of a predetermined decrement in the production of industrial goods, a technical and financial method for the participation of industrial loads has not been proposed.

As mentioned earlier, industrial loads have different equipment that might participate in demand response programs. In [19], the industrial loads which have the ability to respond rapidly with a large amount of power, are introduced. In this work, a method is presented to examine the abilities of these loads in providing the system with ancillary services such as regulation and load following. As can be traced in the reviewed works, a comprehensive and quantitative method which is founded based on the characteristics of loads to prioritize the participation of diverse industries in DRPs for improving the network operation is missing in the literature. Accordingly, designing such an all-inclusive method is the main focus of this paper.

To reach this goal, and in the first step, new variables based on the characteristics of DRPs and industrial processes are defined. These variables, namely *classifying variables* (CVs) are presented in Table I. A criterion namely *Basic Criterion*, which is defined in terms of these variables is then introduced to classify the manufacturing process loads. In the Second Step, a decision-making tree is designed for this classification by which two different levels are taken into consideration. Several classes and subclasses are respectively proposed in Level I and Level II. In Level I, the behaviors of industrial processes are determined in different classes and the associated subclasses are devoted to the main attributes and abilities of their equipment. Once these classes and subclasses are determined, *Participation Coefficient* (*Parti Coef*) is defined to estimate the amount of participation for every class and subclass in the incentive-based programs (IBPs) using the

TABLE I: INDUSTRIAL LOAD CLASSIFYING VARIABLES

Symbol		Quantity
PE	Price Elasticity of Demand	
M	Reduction Magnitude	MWH
D	Load Reduction Duration	H
CLR	Cost of Load Reduction	$\$/MWH$
ND	Notification Duration	min,hour
RU	Ramp-up	MWH/S
RD	Ramp-Down	MWH/S
T	Interval between two Consecutive Load Reduction	day, week
N	Frequency of Load Reduction	$occ/week$

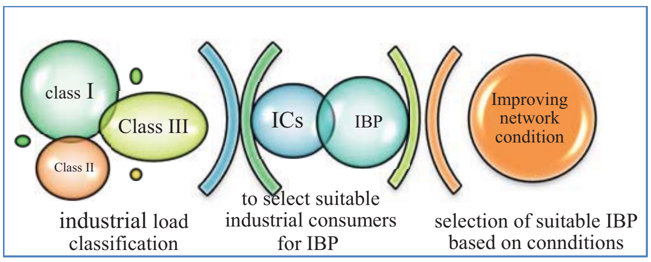

Fig. 1. The outline of this paper

AHP. Running the AHP, industrial load classification (ILC) is quantitatively determined based on the amount of the *parti coef* in the IBPs. In the final step, the *Desirability Coefficient* (*Desirability Coef*) of industrial loads in each subclass for participating in each IBP is estimated. The presented steps within the proposed framework are conceptually delineated in Fig. 1. Compared with the existing works, the main contributions of this paper can be summarized as follows:

- The proposed classification method in this paper can effectively capture the network operational conditions, characteristics of DRPs, the consumers' features, and their requirements.
- The proposed method facilitates the implementation of IBPs in industrial sector and guarantees the satisfaction of various classes of consumers.
- The proposed method quantitatively determines the participation abilities of an industrial consumer in each IBP.

II. Manufacturing Line Load and its Potentials for Participation in IBPs

In order to design a well-organized demand response program for industrial loads, different processes such as cement factory, zinc melting factory, steel plant, and heavy rolling factory have been investigated. As a result of this investigation, it has been found that the common structure of industrial loads is as: (1) lighting loads; (2) heating\cooling loads; (3) manufacturing process loads; and (4) miscellaneous loads. The consumption power of these sectors is highly dependent on the manufacturing process type of industrial consumption. Manufacturing process usually has the highest portion of the total industrial load consumption. This sector is different in various industries based on the share of different devices such as engines, electric furnaces and etc. The load of manufacturing process has different characteristics. One of these characteristics is the *PE* which can be defined as the percentage change of the demand amount proportion to the price change. *PE* is dependent on the load type, manufacturing process specifics, and financial conditions. Industrial load is divided into several sectors in terms of structure. The amount of *PE* is different for every sector of industrial load.

The sectors of the industrial load with *non-zero-elastic demand* include lighting, heating\cooling and emergency\non-emergency ventilation loads. Therefore, price-based DRPs can be implemented for these classes of loads. However, the load of these sectors is usually much lower than the total load of customers. Industrial consumer should trade-off between the profit and cost of participation in DRPs. The other sector of industrial loads with *inelastic demand* is manufacturing process load. This is an important sector of industrial loads. Some consumers are unwilling to interrupt manufacturing process load even with higher prices. Even some industrial consumers prefer to buy at higher price than the delivered energy cost in order to experience less interruptions. Thus, this load sector cannot adopt price-based demand response programs. Despite the importance of interruption limit in manufacturing processes, this load has usually a remarkable share in the total load of industrial customers and therefore only a proper IBP can motivate the customers in adopting DR programs. As shown in Fig. 2, it is valuable to investigate the participation of the manufacturing process loads in IBPs.

TABLE II: Equipment of ML

Industry	TIML	I&ShI	SchML	REWH	ESSE	ESML	OGSE	OGML
Zinc melting								
Glass making								
Tile making								
Paper making								
Cement								
Steel Plant								
Pelletizing								

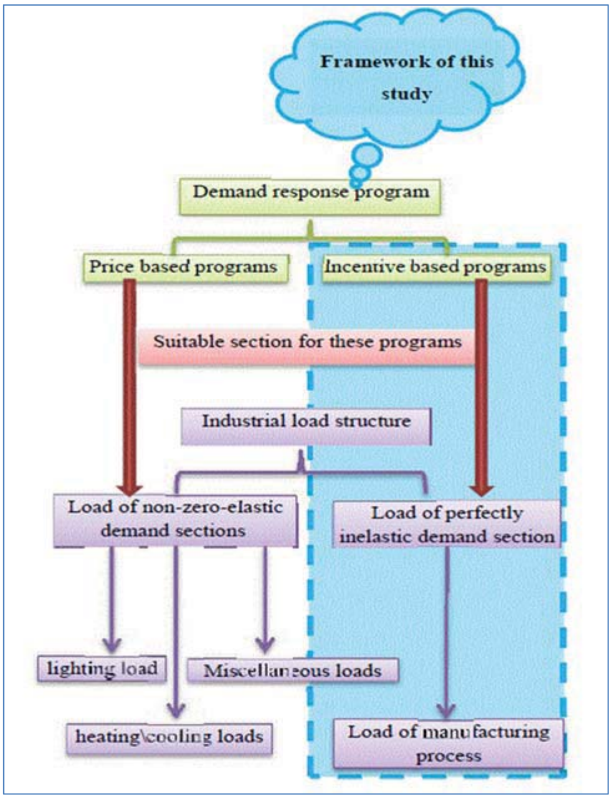

Fig. 2. Framework of this study

In addition to the abovementioned discussions about DRPs for industrial loads, a questionnaire was designed for each customer to identify the potential and actual equipment of the ML for the participant in IBPs. The results of this investigation confirm that the response-ability is somewhat similar in every group of industrial processes with the same capabilities in demand response. For example, different industries such as glass making, tile making, papermaking, cement, steel plant and pelletizing have on-site generation (OG) to supply sensitive equipment. They have almost the same characteristics in load reduction as itemized in Table II. Main equipment of manufacturing process associated with different industries for participant in IBPs is also shown in Table II. The equipment and capabilities that provide demand response possibility for industries can be identified as follows:

A) On-site Generation (OG)

1) The OG as A backup for ML (OGML)

Applying OG is an option for providing the ML of an industry with a back-up. Therefore, the OG provides the entire or a part of the required power for ML while industrial loads should reduce their loads.

2) The OG as the Backup for Sensitive Equipment (OGSE)

Some industries use the OG to supply the required energy of sensitive equipment on the ML in the case that manufacturing process is interrupted due to occurrence of any failure or load reduction notified by Independent System Operators (ISO).

B) Energy Storage (ES)

1) The ES as A Backup for the ML (ESML)

An ES unit is another option for decreasing the required energy of ML delivered from the network. The energy units provide the entire or a part of the required energy of ML while industrial consumers are supposed to reduce their load.

2) The ES as the Backup for Sensitive Equipment (SMES)

Some industries select to deploy ES as a backup for providing the required energy of their manufacturing line sensitive equipment when the ML is interrupted.

C) Warehouse (WH)

1) Reducing Energy Consumption using IM in WH (ERWH)

Some industries usually have WH. Thus, IM can be produced during the times when the price of energy is low and can be stored in the WH. In the case of calling for energy reduction, this IM can be used in the ML.

D) Multi-Product Line (MPL)

1) Energy Reduction by scheduling the ML (SchML)

Some industries have one common ML to produce multiple types of goods. Of course, each kind of good consumes a different amount of energy. It must be considered that only one kind of goods can be manufactured at a time. In such cases, if the reduction of the industrial load is required, industrial consumers can choose to produce the goods which consume the lowest amount of energy at this period.

E) Interruption of ML (IML)

1) Instantaneous & Short Interruption (I&ShI)

ML of some industries can be interrupted immediately after being informed which leads to load reduction. Although the magnitude of this reduction can be considerable, its duration is usually short. In this interruption, the restart cost of the ML is not imposed on consumers.

2) Temporary Interruption of ML (TIML)

The ML in some industries can be interrupted for a long period without causing any damage to equipment. This interruption, namely, temporary interruption, can impose the extra restart cost of manufacturing process on consumers.

Figure 3 briefly represents different types of equipment which affects demand response and illustrates how this equipment acts during the load reduction in industrial center.

III. Theoretical Definition of the Criterion and ILC

As addressed in the previous section, there are different manufacturing processes in industries, while the attributes of the manufacturing process are different from the viewpoint of IBPs. These attributes are determined based on the main type of equipment and how such equipment are used in the manufacturing process. Therefore, it is required to classify the manufacturing processes taking into consideration different attributes of industry customers. In response, an efficient criterion based on the main attributes of the manufacturing process is proposed aimed to classify the industrial loads. *Basic Criterions* for ILC are formulated in terms of *CVs* which are shown in Table I. The *Basic Criterion* is as follows:

$$Basic\ Criterion = [PE, M, D, CLR, ND, RU, RD, T, N] \qquad (1)$$

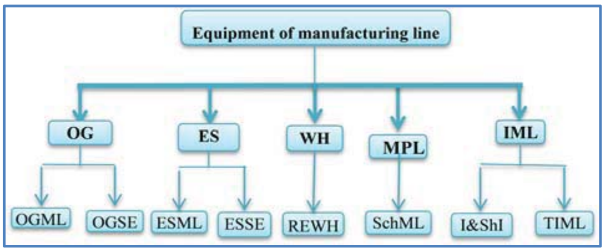

Fig. 3. Different types of equipment impacting the demand response

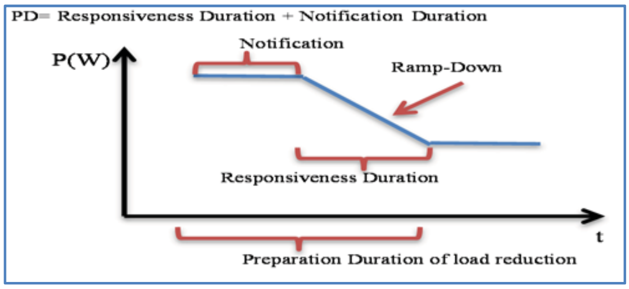

Fig. 4. Load reduction curve in terms of the active power-time

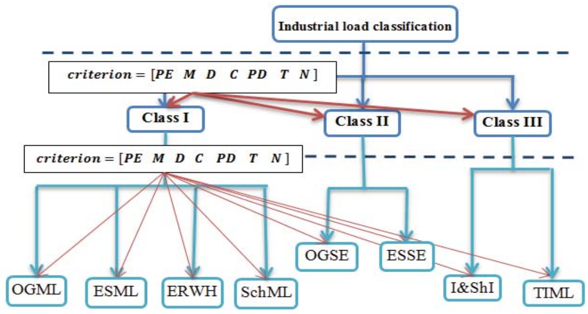

Fig. 5. General structure of the proposed decision-making tree

PE, considered as the *CV* in (1), is defined according to industrial specifics. The other *CV*s, introduced in (1) are defined considering the main features of the IBPs. *CLR*, considered as the *CV* in (1), is defined according to C^{OG}, C^{ES}, C^{WH} , etc. Preparation Duration (*PD*) is considered as a new *CV* instead of *ND*, *RU,* and *RD* in *Basic Criterion*. *PD* is formulated in (2). t_f in (2) is responsiveness duration. Figure 4 demonstrates the load reduction curve based on the active power-time presented *PD*, *ND* and *RD*.

$$PD = ND + RD * t_f \qquad (2)$$

The *Basic Criterion* has been defined as a quantitative equation of the criterion for ILC. It is redefined as follows:

$$Basic\ Criterion = [PE \quad M \quad D \quad CLR \quad PD \quad T \quad N] \qquad (3)$$

A decision-making tree in two levels is here introduced. It is applied from the viewpoint of participants in IBPs. There are several classes in level I of this decision-making tree. These variables present various behaviors of MLs. Each class is categorized into different subclasses in Level II which is done based on the kind of manufacturing line equipment. Figure 5 represents the general structure of the proposed two-level decision-making tree.

The Basic Criterion, named *Evaluation Criterion,* is applied as the equation of criterion for the classes. *Evaluation Criterion* is defined based on the behavior of manufacturing process. The behavior of manufacturing process in facing IBPs is dependent on the responsiveness ability and also the flexibility of the ML. Three classes for industrial loads in level I of the decision-making tree are introduced as follows:

- **Class I:** Load reduction can be done without any interruption in goods production.
- **Class II:** Load reduction can be done in standby mode of the ML.
- **Class III:** Load reduction can be done in interrupted mode of the ML.

Meanwhile, every class includes several subclasses which are introduced later in the manuscript.

A) Class I

The industries in Class I have either the energy backup equipment such as OG, WH and ES or capabilities such as manufacturing line scheduling in order to decrease the required power from the network. These backup equipment can be used partly or in full to decrease the required power for a short time period. This means that the ES and WH transfer the required power of ML to another time. A main feature of such industries in this class is that despite non-interruption of goods production, they can participate in IBPs. The participation cost of this class is dependent on the cost of keeping the backup equipment such as OG, ES and etc.

B) Class II

In this class, the ML of industries is interrupted in response to IBPs. However, their sensitive equipment is kept in the standby mode. The OG and ES are applied to supply the required energy of sensitive parts of the ML in the standby mode such as automation equipment, furnace, etc. As a result, these industries may lose the profit of goods production. These consumers suggest a participation cost which includes maintenance costs of backup equipment and damage cost of goods production interruption.

C) Class III

The ML of the industries in Class III can be totally interrupted for participating in IBPs while it is producing the goods. After the interruption of the ML occurs, the process can be completed without mechanical damages of process equipment and safety concerns. However, these consumers lose benefit of goods production in responding to these IBPs.

As can be seen in the previous explanation, each class is categorized into different subclasses in Level II. *Basic Criterion* is applied for every subclass. *Basic Criterion* is named in each subclass to a name which is proportional to the subclass's characteristics. The characteristics for every subclass are defined based on the equipment features of ML. In other word, *CV*s of the criterion are formulated based on the responsiveness characteristic of its equipment and capabilities in every subclass. The subclasses of Class I, Class II and Class III are respectively expressed in the following:

***A) Class I**:* There are four subclasses in class I explained in the following:

1) The OG as a Backup for ML (OGML)

OGML is considered as a subclass of Class I. Its criterion is named OG_{IC}^{NSP}. The *CV*s and constraints of OG_{IC}^{NSP} are formulated based on the characteristic of OG shown in (4).

2) ES as a Backup for ML (ESML)

ESML is considered as a subclass of Class I. Its criterion is named ES_{IC}^{NSP}. The *CV*s and constraints of its criterion are formulated based on the characteristic of ES shown in (5).

3) Reducing Energy Consumption by using IM in WH (ERWH)

ERWH is considered as a subclass of Class I. Its criterion is named WH_{IC}^{NSP}. The CVs and constraints of WH_{IC}^{NSP} are formulated based on the characteristics of WH shown in (6).

3) *Energy Reduction by Scheduling the ML (SchML***)**

SchML is considered as a subclass of Class I. Its criterion is named Sch_{IC}^{NSP}. The CVs and constraints of Sch_{IC}^{NSP} are formulated based on the characteristics of intermediate material into WH shown in (7).

B) Class II: There are two subclasses in Class II explained in the following:

1) OG as a Backup for Sensitive Equipment (OGSE)

OGSE is considered as a subclass of Class II. Its criterion is named OG_{IC}^{SP}. The *CV*s and constraints of OG_{IC}^{SP} are formulated based on the characteristic of OG and ML shown in (8).

2) ES as a Backup for Sensitive Equipment (ESSE)

ESSE is considered as a subclass of Class II. Its criterion is named ES_{IC}^{SP}. The *CV*s and constraints of ES_{IC}^{SP} are formulated based on the characteristic of ES and ML shown in (9).

Class I

$$OG_{IC}^{NSP} = [PE, M, D, CLR, PD, T, N] \tag{4}$$

$PE = 0, M = P^{OG}$ $\quad D = T^{on,OG}$

$CLR = C^{OG}$ $\quad ND = ST^{min,OG} + RU^{OG} * t_{on}$

$T = T^{off,OG}$ $\quad N = N^{st,OG}$

$const: P^{min,OG} < P^{OG} < P^{max,OG}, C^{OG} = C_{ST} + C_P + C_{PE}$

$$ES_{IC}^{NSP} = [PE, M, D, CLR, PD, T, N] \tag{5}$$

$PE = 0, \; M = P^{ES}$ $\quad D = E^{ES}/P^{ES}$

$CLR = C_{ES}$ $\quad ND = ST^{min,ES} + RC^{ES} * t_{on}$

$T = min(T^{CP}/MN^{ES}, ERT^{ES})$ $\quad N = MN^{ES}$

const: $P^{ES} < P^{max,ES}$, $D < E^{max,ES}/P^{ES}$

$$WH_{IC}^{NSP} = [PE, M, D, CLR, PD, T, N] \tag{6}$$

$PM = AMM^{used,WH} * P^{CPT}$ $\quad D = AMM^{WH}/A^{Houre,PLI}$

$CLR = C_{WH}$ $\quad ND = D^{EIG} + RL^{NPL} * t_{off}$

$T = AMM^{max,WH}/AMM^{H,PLI}$ $\quad N = MN^{WH}$

const: $AMM^{used,WH} < AMM^{max,WH}$

$$Sch_{IC}^{NSP} = [PE, M, D, CLR, PD, T, N] \tag{7}$$

$PE = 0, M = PC^{GML} - PC^{LEC}$ $\quad D = D^{LGP}$

$CLR = C_{PMP}$ $\quad ND = D^{LLPL} + ShD^{GPL}$

$T = max(D_{LGL}^{TL}, D_{PGL}^{TS})$ $\quad N = min(N_{LGL}^{PL}, N_S^{PL})$

$const: \; PC^{PL} \leq PC^{HEC}$

Class II

$$OG_{IC}^{SP} = [PE, M, D, CLR, PD, T, N] \tag{8}$$

$PE = 0, \; M = PC^{ML}$ $\quad D = T^{on,OG}$

$CLR = C_{SP}^{OG} + C_{PS}$ $\quad ND = ST^{min,OG} + RS^{ML} * t_{on}$

$T = T^{off,OG}$ $\quad N = N^{st,OG}$

$const: PC^{ML} \leq PC^{ML,max}$, $RU = RS^{ML}$

$$ES_{IC}^{SP} = [PE, M, D, CLR, PD, T, N] \tag{9}$$

$PE = 0, \; M = PC^{PL}$ $\quad D = T^{DCH,ES}$

$CLR = C_{SP}^{ES} + C_{PS}$ $\quad ND = ST^{min,ES} + RS^{PL} * t_{on}$

Class III

$$I\&ShI_{IC}^{SP} = [PE, M, D, CLR, PD, T, N] \tag{10}$$

$PE = 0, \; M = PC^{ML}$ $\quad D = T^{off,ML}$

$CLR = C_{PS}$ $\quad ND = ShD^{GML} + RS^{ML} * t_{off}$

$T = D_{PGL}^{TS}$ $\quad N = MN^{off}$

$const: \; PC^{ML} \leq PC^{ML,Max}$

$$TIML_{IC}^{SP} = [PE, M, D, CLR, PD, T, N] \tag{11}$$

$PE = 0, \; M = PC^{ML}$ $\quad D = T^{off,ML}$

$CLR = C_{PS}$ $\quad ND = ShD^{GML} + RS^{ML} * t_{off}$

$T = D_{PGL}^{TS}$ $\quad N = MN^{off,T}$

$Const: \; PC^{ML} \leq PC^{ML,Max}$

C) Class III: There are two subclasses in Class III explained in the following:

1) Instantaneous & Short Interruption (I&ShI)

I&ShI is considered as a subclass of Class III. Its criterion is named $I\&ShI_{\mathrm{IC}}^{\mathrm{SP}}$. The *CV*s and constraints of $I\&ShI_{\mathrm{IC}}^{\mathrm{SP}}$ are formulated based on the interruption characteristic of ML shown in (10).

2) Temporary Interruption of ML (TIML)

TIML is considered as a subclass of Class III. Its criterion is named $TIML_{\mathrm{IC}}^{\mathrm{SP}}$. The *CV*s and constraints of $TIML_{\mathrm{IC}}^{\mathrm{SP}}$ are formulated based on the interruption characteristic of ML shown in (11). The above mentioned is a theatrical explanation on the criterion of the proposed classification for inelastic demand sector of the industrial load.

IV. Analytical Hierarchical Classification Method

In this section, the AHP method is borrowed to classify different industrial loads regarding the main features of MLs, the viewpoint of consumers and other important factors. To reach this goal, at first, the AHP is employed to evaluate the introduced quantity criterion for the classes and subclasses addressed in levels I and II. With these criteria, a number of similar industries are placed in each subclass. Participation of the industries in each subclass is assessed based on the corresponding criterion in their class and subclass by assuming that the participation opportunity is equal for all consumers in IBPs regardless of the goods type, final expense of goods production and production profit of goods. Meanwhile, consumers can submit a price for participating in IBPs according to CLR and a selective profit margin. The selective profit margin ($/MWh) is proportional to the network operating conditions and consumers' willingness. This method for assessing the ILC is named *Analytical hierarchical classification method* (AHCM).

A. Main Principles of AHCM

In this part, the main principles of the AHCM are explained. In this method, the pairwise comparison matrix is used to evaluate the criteria. The pairwise comparison matrix can be constructed by

$$I^P = [I_{lm}^P] \quad l, m = \text{Num of Elements} \quad (12)$$

I_{lm}^P is achieved by using fundamental scales in AHP. The scale ranges from 1/9 for "least valued than", through 1 for "equal", to 9 for "absolutely more important than" covering the entire spectrum of the comparison [17]. $\mathrm{I}_{\mathrm{lm}}^{\mathrm{P}}$ represents the mutual importance degree of the element *L* relative to element *m* from the viewpoint of *P*. *P* in (12) is one of *CV*s such as *EP, M*, *D*, *CLR*, *PD*, *T* and *N*. As mentioned before *EP* is one of the *CV*s, which is considered almost zero for the manufacturing process load. Therefore, *EP* is not considered in the pairwise comparisons. $Criterion_i^P$ is an array of the criterion matrix from the viewpoint of *P*, that is:

$$Criterion_i^P = \frac{\sum_{\forall m}\left(\frac{I_{lm}^P}{\sum_{\forall l} I_{lm}^P}\right)}{n(m)} \quad i = num\,of\,level \quad (13)$$

When the pairwise comparison matrix is assessed for every level, the criterion for the element in every level is obtained using (13) together with the pairwise comparison matrix of its level. In the proposed method, *Parti Coef* is earned for industries of each subclass in form of a matrix. Its array is calculated by (14). $Parti\,Coef_n^P$ determines the participation of the industries in subclass *n* from viewpoint of *P*.

$$Parti\,Coef_n^P = \Pi_i^{imax} Criterion_i^P \quad i = Num\,of\,Level \quad (14)$$

B. Implementation Procedure of AHPM

The Evaluation Criterion is calculated for each Class in level I. In order to assess it for each class, a pairwise comparison matrix is needed for all classes based on CVs. This matrix is obtained according to the characteristics of classes which are qualitatively explained in Table III. It is obtained for each class in level I in terms of the CVs using (13) as explained in the following:

$Eval\,Crit^{Class\,I} = [0, 0.13, 0.70, 0.70, 0.73, 0.58, 0.69]$

$Eval\,Crit^{Class\,II} = [0, 0.50, 0.23, 0.10, 0.09, 0.33, 0.23]$

$Eval\,Crit^{Class\,III} = [0, 0.38, 0.07, 0.20, 0.13, 0.08, 0.09]$

The criterion is calculated for each subclass in level II such as OG_{IC}^{NSP}, ES_{IC}^{NSP}, etc. These criteria are in form of matrix formulated in (5)-(11) which are obtained by AHP. It is also necessary to calculate the pairwise comparison matrix for all the subclasses of each class. Therefore, a pairwise comparison matrix is earned for subclasses of each class. Each array of the criterion such as OG_{IC}^{NSP}, ES_{IC}^{NSP}, etc. is obtained by (13) and its pairwise comparison matrix. Here, *n (m)* and *n* in (13) are respectively the number of the subclasses in each class and the subclass type. The criterion for subclasses of each class is determined by (13) addressed in detail in the following:

Class I: Qualitative comparison for the subclasses of class I is shown in Table IV. The criterion for these subclasses in terms of *CVs* is obtained by (13) as shown in the following:

OGML: $OG_{IC}^{NSP} = [0.45, 0.45, 0.109, 0.073, 0.73, 0.164, 0.164]$

ESML: $\mathrm{ES}_{\mathrm{IC}}^{\mathrm{NSP}} = [0, 0.3, 0.05, 0.07, 0.16, 0.11, 0.07]$

ERWH: $WH_{\mathrm{IC}}^{\mathrm{NSP}} = [0, 0.2, 0.25, 0.16, 0.11, 0.07, 0.11]$

SchML: $Sch_{\mathrm{IC}}^{\mathrm{NSP}} = [0, 0.05, 0.25, 0.655, 0.655, 0.655, 0.655]$

Class II: Qualitative comparison for the subclasses of Class II is shown in Table V. The criterion for these subclasses in

TABLE III: Qualitatively Comparison for the Classes

CV	Comparison	CV	Comparison
M	Class II≤ Class III< Class I	PD	Class II≤ Class III< Class I
D	Class I≤ Class II < Class III	T	Class III≤ Class II< Class I
CLR	Class II≤ Class III< Class I	N	Class I≤ Class II< Class III

TABLE IV: Qualitative comparison of the Subclasses of Class I

CV	Comparison	CV	Comparison
M	ERWH<SchML<ESML<OGML	PD	ERPM<OGML<ERWH<ESML
D	ESML<SchML<ERWH<OGML	T	SchML<OGML<ESML<ERWH
CLR	SchML<ESML<ERWH<OGML	N	ESML<ERWH<OGML<SchML

TABLE V: Qualitative comparison of the subclasses of class II

CV	Comparison	CV	Comparison	CV	Comparison
M	I&ShI<TIML	CLR	TIML<I&ShI	T	TIML<I&ShI
D	TIML<I&ShI	PD	TIML<I&TMI	N	I&ShI<TIML

TABLE VI: Qualitative comparison for subclasses of Class III

CV	Comparison	CV	Comparison	CV	Comparison
M	I&ShI<TIML	CLR	TIML<I&ShI	T	TIML<I&ShI
D	TIML<I&ShI	PD	TIML<I&TMI	N	I&ShI<TIML

TABLE VII: Participation Coefficient for Subclasses

Class	Subclass	Criterion	PC^M	PC^D	PC^{CLR}	PC^{PD}	PC^T	PC^N
I	ESML	$ES_{\mathrm{IC}}^{\mathrm{NSP}}$	0.0065	0.0665	0.336	0.20659	0.2784	0.30636
	OGML	$OG_{\mathrm{IC}}^{\mathrm{NSP}}$	0.0585	0.3003	0.112	0.04161	0.1392	0.15318
	ERWH	$WH_{\mathrm{IC}}^{\mathrm{NSP}}$	0.026	0.203	0.168	0.0657	0.0928	0.1518
	SchML	$OG_{\mathrm{IC}}^{\mathrm{NSP}}$	0.039	0.133	0.084	0.4161	0.0696	0.0759
II	OGSE	OG_{IC}^{SP}	0.4	0.19159	0.025	0.0162	0.23562	0.1725
	ESSE	ES_{IC}^{SP}	0.1	0.03864	0.075	0.0738	0.09504	0.0575
III	I&ShI	$I\&ShI_{IC}^{SP}$	0.304	0.01169	0.15	0.1066	0.05712	0.0675
	TIML	$TIML_{IC}^{SP}$	0.076	0.05824	0.05	0.0234	0.02304	0.0225

terms of *CVs* is obtained by (13) as shown in the following:

OGSE: OG_{IC}^{SP} = [0,0.8, 0.833,0.25,0.18,0.714,0.75]

ESSE: ES_{IC}^{SP} = [0,0.2, 0.168, 0.75, 0.82, 0.288, 0.25]

CLASS III: The qualitative comparison for the subclasses of Class III is based on the CVs shown in Table VI. The criterion for these subclasses in terms of CVs is obtained by (13) as shown in the following:

I&ShI: $I\&ShI_{IC}^{SP}$ = [0,0.8,0.167,0.75,0.82,0.714,0.75]

TIML: $TIML_{IC}^{SP}$ = [0,0.2, 0.832, 0.25, 0.18, 0.288, 0.25]

Once the introduced criterion is estimated, *Parti Coef* of the industries in each subclass is obtained by (14) shown in Table VII. It is a matrix in terms of the *CV*s. ISO and industry customers can achieve the following strategic results:

(1) ISO uses the *Parti Coef* and compares industries of different subclasses in terms of CVs in quantitative terms. This will help ISO to identify the change spectrum of each component of the *Parti Coef* among industries of different subclasses. For example, its array amount such as P^{CM} for all subclasses is shown in the first column of Table VIII. The P^{CM} change range in this column is $0.0065 \leq P^{CM} \leq 0.4$, which is the minimum and maximum respectively related to the industries of the ESML and OGSE subclasses. ISO will recognize that the *M* is fewer for the industries of OGSE and ERWH subclasses and will inform them to improve it. Industrial consumers will decide on managing their optimization based on the return on their investment through participation in IBPs.

(2) ISO surveys the array amount of the *Parti Coef* for the industrial loads of different subclasses and determines their load reduction behavior in terms of *CV*s. The load reduction characteristics of industrial loads in each subclass alone may not provide the necessary condition for a selective load response program. In this case, the industries of several subclasses are grouped to provide the features of the chosen program. For example, an EDRP is called for an unplanned event. EDRP has two important characteristics such as: (1) the *PD* is very Low, (2) M is very high. The ISO coordinates the industries of two subclasses, named ESML and ESSE, together in this condition, since the PD of ESML (PC^{PD} =0.20659) and M of ESSE (PC^{M} =0.1) are low and high, respectively. Thus, the coordinated participation of industries in these two subclasses can be more appropriate in this program.

(3) The *Parti Coef* supplies quantitative visibility to industrial consumers of different subclasses on how much is invested in improving *CV*s to optimize the participation in IBPs. For example, *PD* and *CLR* towards other *CV*s are not suitable from industrial loads of OGSE. Therefore, these consumers are encouraged to improve *PD* and *CLR* so that these variables reach the desirable levels until they can participate in the competition.

(4) If there are participants from different subclasses and they compete for selection in one of the programs, the characteristics of the industrial loads are determined in ILC. The choice of consumers is easy because their differences can be expressed quantitatively.

V. DESIRABILITY OF DIFFERENT INDUSTRIAL LOADS IN IBPS

In the previous section, the steps for assessing ILC and *Parti Coef* for industrial loads were discussed. From the viewpoint of a system operator, it is important to distinguish the abilities of industrial loads in IBPs with the goal of improving the system operation. Hence, a coefficient, named *desirability coef* of the industrial loads, is defined to determine participation impact for $A = \pi r^2$e programs such as direct load control (DLC), interruptible or curtailable rate program (I/C Rate), EDRP, capacity-market program (CMP), ancillary service market program (ASMP), and demand bidding /buyback Program (DB/BP).

A. Industrial Load Desirability in IBPs

It is necessary to obtain the desirability of industries in each IBP. This goal can be achieved with the following two actions:

Action 1: Industrial loads are classified. This classification determines the industrial loads of each subclass. The participation of each subclass is expressed in terms of *CV*s. This action is done based on the procedure in Section IV.

Action 2: The importance of each program is achieved in terms of the *CV*s. It, named *weight coef*, is in the form of matrix. The importance of each program from the viewpoint of *P* is calculated with WC_{IBP}^{P}. Meanwhile, the pairwise comparison matrix is earned for IBPs according to the ISO's experience and characteristics of the programs. WC_{IBP}^{P} is formulated as:

$$\mathrm{WC}_{IBP}^{P} = \frac{\sum_{\forall m}\left(\frac{I_{lm}^{P}}{\sum_{\forall l} I_{lm}^{P}}\right)}{n(m)} \qquad (15)$$

Where, WC_{IBP}^{p} is an array of *weight coef* based on the *P*. I_{lm}^{P} in this matrix is the mutual importance degree between two programs *L* and m from the viewpoint of *P* in IBP. Here, *n (m)* and *n* in (15) are respectively the numbers of the IBPs and the IBP type. $Desirability\ Coef_{IBP}^{n,p}$ is formulated as:

$$Desirability\ Coef_{IBP}^{n,P} = \sum_{p}^{n(P)} WC_{IBP}^{p}.Parti\ Coef\ _{n}^{P} \qquad (16)$$

TABLE VIII: CHARACTERISTICS OF IBPS

IBP	characteristics of IBP
I/C Rate	-largest customers (200 kW for the base interruption to 3 MW) -Reduction within 30-60 min of being notified by the utility -capping the number of times or hours that a utility can call interruptions - periods of high demand for the energy or shortage generation - not being good for customers with 24 hour-a-day, seven-days-a-week operations or continuous processes
EDRP	-reducing their loads during reliability-triggered events and periods of reserve shortage, but curtailment is voluntary -participants in the programs do not receive capacity payments -its use in grid operation and planning
CMP	- minimum load reductions of 100 kW - two-hour notification - minimum four-hour reduction - reserve shortage event
DB/BP	-large customers -Min and max load reductions are 2 and 4 hours, respectively -Day-ahead notification - Peak load, Incident, High Price
ASMP	-consumers must be able to adjust load quickly when a reliability event occurs - The response duration depends on the nature of the event and the type of reserve being supplied, but is typically provided in minutes rather than the hours required when peak shaving or responding to price signals. - These short timeframes and program requirements limit the type of resources that can participate. - operating reserves, non-spin and replacement reserve and supplemental energy markets - These resources could include large ICs that can be safely curtailed quickly without harm to equipment

TABLE IX: WEIGHT COEFFICIENT FOR THE IBPS

p	WC_{IP}^{P}	WC_{EDRP}^{P}	WC_{CP}^{P}	WC_{ASP}^{P}	$WC_{DB/BBP}^{P}$
M	0.384	0.107	0.219	0.088	0.55
D	0.1918	0.134	0.437	0.077	0.092
CLR	0.042	0.06	0.05	0.07	0.06
PD	0.108	0.532	0.061	0.62	0.139
T	0.092	0.076	0.087	0.077	0.069

TABLE X: DESIRABILITY COEF OF INDUSTRY IN THE IBPS

Class	Subclass	I/C Rate	EDRP	CMP	ASMP	DB/BP
I	SchML	0.133	0.188	0.129	0.200	0.11
	OGML	0.130	0.100	0.187	0.083	0.1
	ERWH	0.099	0.096	0.137	0.088	0.07
	ESML	0.109	0.260	0.113	0.288	0.11
II	OGSE	0.25	0.11	0.22	0.09	0.27
	ESSE	0.08	0.07	0.06	0.07	0.09
III	I&ShI	0.154	0.11	0.101	0.113	0.202
	TIML	0.051	0.035	0.051	0.033	0.057

$Desirability\ Coef_{IBP}^{n}$ is an array of the desirability matrix for the industries with subclass n in each IBP. In (16), $Parti\ Coef\ _{n}^{P}$ is an array of the *Parti Coef* for subclass *n* based on *P* which is achieved in Section IV.

$$\sum_{n}^{n\,max} Desirability\ Coef_{IBP}^{n,P} = 1 \qquad (17)$$

IBP in (17) is one of IBPs such as I/C Rate, EDRP, CMP, ASMP and DB/BP.

B. Numerical Study based the ISO's Experience and Programs Characteristics

In order to numerically investigate the proposed framework to achieve the desirability of industrial loads in each IBP, the following actions are done:

(1) *Parti Coef*, calculated for industries of each subclass shown in Table VII, is used.

(2) The *Weight Coef* can be obtained for each IBP in terms of CVs shown in Table IX. This has been accomplished through the pairwise comparison matrix for IBPs based on the characteristics of IBPs shown in Table VIII. Then *Weight Coef* is earned by (15) and pairwise comparison matrix of IBPs. The *Desirability Coef* of industrial loads in each IBP is found with the *Weight Coef* and the *Parti Coef* shown in Table X.

The strategic results from the *Desirability Coef* in Table X are:

(1) ISO will prioritize industries of subclasses based on the desirability of industries in each program. For example, prioritization of these subclasses in I/C Rate is as follows: OGSE, I&ShI, SchML, OGML, ESML, ERWH, ESSE and TIML. Therefore, the industries of these subclasses are called back in the order of priority for this program.

(2) ISO investigates industries of the subclasses based on this coefficient and identifies those with little participation in the programs. If such programs are tailor-made to the characteristics of industrial loads, they can be more involved in such programs.

VI. CONCLUSIONS

This paper introduces an ILC method with the goal of assessing the relationship among the characteristics of DRPs and industrial loads. This framework identifies the diversity in industrial loads in an accurate and quick manner; it also quantitatively expresses the importance and similarity of various industrial lines. In this regard, a two-level decision-making algorithm was developed and the steps for implementation of this algorithm were discussed. Applying the proposed framework on different industrial customers in a region in Iran, it was shown that in general, the load of ML is more suitable for IBPs. With a quantitative indicator, namely, *Desirability Coef*, a mechanism was provided on which industrial process load is more compatible with each IBP.

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