

# Analysis on Influencing Factors of Demand Response Implementation Barriers

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**Abstract:** According to the ISM (Interpretative Structural Model) method, this paper analyzed the hierarchical relationship between the main factors which affected the implementation barriers of demand response. 14 main influencing factors were divided into three levels based on the result of reachability matrix and the ISM: deep factors, middle factors and surface factors. Then, the influence of each factors was sorted in the light of analytic network process (ANP), so the comprehensive ranking of the indexes is determined. The conclusion was that the main factors affecting the implementation barriers of DR were mainly focused on regulatory system, cost recovery mechanism, market mechanism and promotion.

**Keywords:** Demand Response, ISM, ANP, Implementation Factors

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## 1. Introduction

China now is in a period of rapid economic development. To achieve the aim at building a moderately prosperous society and improve residents' living standards, the consumption of energy will continue growing. Electricity as a basic energy, cannot be stored in large numbers and must maintain the balance between supply and demand, therefore, strict operation and regulation are necessary to meet the peak load demand. To reduce the externality and improve the efficiency of the electricity system, after the energy crisis of the 1970s, the U. S. introduced DSM (Demand Side Management) into electric power planning. With the development of electricity market, the beneficiaries of electricity market are diversified gradually, besides, economic measures and incentives policy are implemented were used to optimize the utilization.

Demand response means that the demand side or terminal users change their consumption patterns (consumption time or level) according to price signals and incentives of the market or direct command from system operators. In the past, the only way to adapt to the development on electricity systems is building more power generation and transmission facilities. However, since the DR is based on the deregulation of retail price and the improvement of demand elasticity,

after the introduction of DR, the role of demand side in the market is increasingly important through the price signal and incentive mechanism. As a result, it helps to keep balance between supply and demand with a relatively low cost and provide greater flexibility for the reliable operation of the grid [1-2].

Many countries have placed demand side resource at the same or even higher priority with the supply side resource considering energy strategy, besides, the concept of DR has been widely accepted and technically there's no restrictive barriers, the development of DR projects are not achieve the desired level yet. Therefore, this paper will analyze the factors affecting the implementation barriers of DR by ISM and AHP methods.

## 2. Hierarchical Structure of Influencing Factors

ISM was proposed in 1973, which was mainly used to analyze the elements in a complex system and their interdependence and mutual restraint relationship. The basic principle of ISM is decomposing the elements off the complex system into several sub-elements, then according to

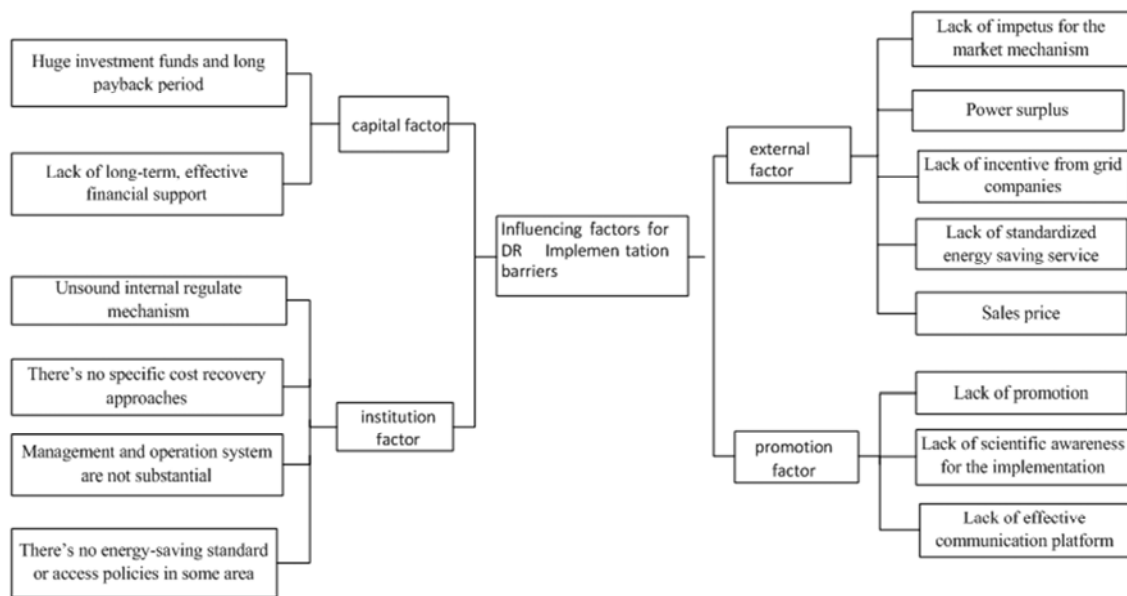
theoretical knowledge, practical experience and software, combine those elements into a multi-level hierarchical structure.

In order to maximize the reliability of the evaluation, this paper selected 36 alternatives and invited 12 DSM experts to supplement and screen. This paper used Delphi approaches to select the evaluation index. The main obstacles factors in the implementation of DR are shown in table 1.

According to table 1, the index system of influencing factors for DR implementation barriers is available, which is shown in Figure 1.

**Table 1.** Main barrier factors for the implementation of DR.

Serial Number	barrier factors
S <sub>1</sub>	Lack of scientific awareness for the implementation
S <sub>2</sub>	Huge investment funds and long payback period
S <sub>3</sub>	Lack of impetus for the market mechanism
S <sub>4</sub>	Lack of effective communication platform
S <sub>5</sub>	Sales price
S <sub>6</sub>	Unsound internal regulate mechanism
S <sub>7</sub>	Power surplus
S <sub>8</sub>	Lack of long-term, effective financial support
S <sub>9</sub>	Lack of incentive from grid companies
S <sub>10</sub>	There's no specific cost recovery approach
S <sub>11</sub>	Lack of standardized energy saving service
S <sub>12</sub>	Lack of promotion
S <sub>13</sub>	Management and operation system are not substantial
S <sub>14</sub>	There's no energy-saving standard or access policies in some area



**Figure 1.** The index system of influencing factors for DR implementation barriers.

## 2.1. Establish Adjacency Matrix

Based on Table 1, adjacency matrix represents the collection of influencing factors of DR implementation barriers:  $A = (a_{ij})_{14 \times 14}$ , as is shown in table 2, in which  $a_{ij} = \{1: \text{If there's a direct influence relationship between } s_i \text{ and } s_j; 0: \text{if there's no direct influence relationship between } s_i \text{ and } s_j.\}$

**Table 2.** Adjacency matrix.

	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>	S <sub>13</sub>	S <sub>14</sub>
S <sub>1</sub>	0	0	0	0	0	0	0	0	1	0	0	0	0	0
S <sub>2</sub>	0	0	0	0	1	0	0	1	0	1	0	0	0	0
S <sub>3</sub>	0	0	0	0	0	0	0	0	0	0	0	0	1	0
S <sub>4</sub>	1	0	0	0	0	0	0	0	0	0	0	1	0	0
S <sub>5</sub>	0	0	0	0	0	0	0	1	1	0	0	0	0	0
S <sub>6</sub>	0	0	0	0	0	0	0	0	0	0	0	0	1	1
S <sub>7</sub>	0	0	1	0	0	0	0	0	0	0	1	0	0	0
S <sub>8</sub>	0	0	0	0	0	0	0	0	0	0	0	0	1	0
S <sub>9</sub>	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S <sub>10</sub>	0	0	0	0	0	0	0	1	0	0	0	0	1	0
S <sub>11</sub>	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S <sub>12</sub>	1	0	0	1	0	0	0	0	0	0	0	0	0	0
S <sub>13</sub>	0	0	0	0	0	0	0	0	0	1	0	0	0	0
S <sub>14</sub>	0	0	0	0	0	0	0	0	0	0	1	0	0	0

## 2.2. Reachability Matrix

The adjacency matrix  $A$  is used to construct the  $A + I$  matrix, in which the  $I$  represents the identity matrix; According to Boolean algebra algorithm, the adjacency matrix  $A=A+I$ , If  $A \neq A^2 \neq A^3 \dots \neq A^{r-1} = A^r$ , the reachability matrix is  $T=A^{r-1}$ . This paper used Matlab to do the calculation job. Since  $(A+I)^6=(A+I)^5 \neq (A+I)^4 \dots \neq (A+I)$ , the reachability matrix is  $M=(A+I)^5$ , shown as the following:

$$M = \begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 1 \end{bmatrix}$$

In order to facilitate the focus, it's necessary to divide the Influencing Factors of DR Implementation into different levels based on the reachability matrix. Therefore, the concepts of reachable collection and antecedent collection are introduced. The reachability collection of  $s_i$  refers to a set of factors in the  $s_i$ -th row of 1 in the reachability matrix, and recorded as  $R(s_i)$ . The concepts of antecedent collection  $s_j$  refer to a set of factors in the  $s_j$ -th line of 1, and recorded as  $P(s_j)$ . The calculation results of  $R(s_i)$  and  $P(s_j)$  are shown in table 3.

**Table 3.** Calculation results of  $R(s_i)$ ,  $P(s_j)$  and  $R(s_i) \cap P(s_j)$ .

Factor $s_i$	Reachable Collection $R(s_i)$	Antecedent Collection $P(s_i)$	$R(s_i) \cap P(s_i)$
$s_1$	1, 3, 8, 9, 10, 13,	1, 4, 13,	1, 13
$s_2$	2, 3, 5, 8, 9, 10, 13,	2	2
$s_3$	3, 8, 10, 13,	1, 2, 3, 4, 5, 7, 9, 12	3
$s_4$	1, 3, 4, 8, 9, 10, 12, 13,	4, 12	4, 12
$s_5$	3, 5, 8, 9, 10, 13	2, 5	5
$s_6$	6, 8, 10, 11, 13, 14	6	6
$s_7$	3, 7, 8, 10, 11, 13, 14	7	7
$s_8$	8, 10, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14	8, 10, 13
$s_9$	3, 8, 9, 10, 13	1, 2, 4, 5, 9, 12	9
$s_{10}$	8, 10, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14	8, 10, 13
$s_{11}$	8, 10, 11, 13, 14	6, 7, 11, 14	11, 14
$s_{12}$	1, 3, 4, 8, 9, 10, 12, 13	4, 12	4, 12
$s_{13}$	8, 10, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14	8, 10, 13
$s_{14}$	8, 10, 11, 13, 14	6, 7, 11, 14	11, 14

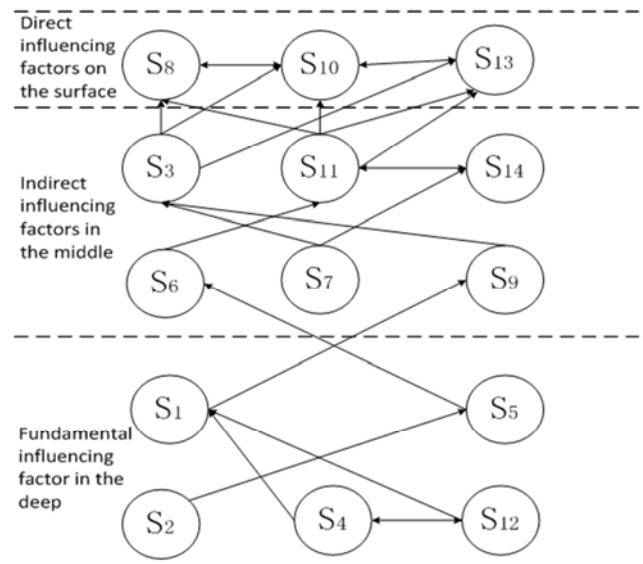
Based on table 2, the risk factors are divided as follows:  
If  $s_i$  meet the condition that

$$R(s_i) \cap P(s_i) = R(s_i)$$

$S_i$  is the top priority set. So according to table 2, the first degree system is  $L_1 = \{S_8, S_{10}, S_{13}\}$ ; Delete the row and line containing  $L_1$  in the reachability matrix and get a new matrix  $M$ , according to the steps above, the second layer system  $L_2 = \{S_3, S_{11}, S_{14}\}$  is obtained. The rest can be done in the same way: the third layer system is  $L_3 = \{S_6, S_7, S_9\}$ ; the forth layer system is  $L_4 = \{S_1, S_5\}$ ; the fifth layer system is  $L_5 = \{S_2, S_4, S_{12}\}$ .

## 2.3. Establish the ISM Model of Influencing Factors

The factors in reachability matrix  $M$  are arranged in the order of layers, and the hierarchical relationship of those factors is available after removing the unit matrix. The ISM diagram for influencing factors of DR implementation barriers is shown in Figure 2.



**Figure 2.** ISM diagram for influencing factors of DR implementation barriers.

## 2.4. ISM Analyze

The Figure 1 shows that the influencing factors of DR implementation barriers can be divided into 5 levels, including surface factors, intermediate factors and deep factors

### 2.4.1. Direct Influencing Factors on the Surface

Lack of long-term, effective financial support, lack of specific cost recovery approaches and Management and operation system are not substantial are the surface factors. Those three aspects can directly influence the implementation of DR. Therefore, from this perspective, the only way to implement DR better is perfecting the institution and establishing capital investment and recovery mechanism for the technical support system at the same time.

### 2.4.2. Indirect Influencing Factors in the Middle

The influencing factors in the middle layer can not only have indirect effects on the implementation of DR, but also have a restrictive effect on the surface factors. The essence of DR is using market price mechanism and incentive mechanism to inspire the competition and collaboration of all the market participants, aiming to reduce the cost, maintain the operation safe and reliable and improve resource efficiency. Meanwhile, policy plays an important role in the implementation of DR. Only by perfecting the incentive policies and promoting the healthy development of energy-saving companies can establish better financing channels and promoting the effective implementation of DR.

### 2.4.3. Fundamental Influencing Factor in the Deep

There's a lot of influencing factors to DR, as a result, multi-unit cooperation is needed to ensure it progress smoothly instead of individual effort. So the government should step up publicity efforts including television, newspapers, public service ads, seminars and other activities to strengthen the awareness of DR. Besides, funds are the guarantee for the long-term and effective implementation of DR. The relevant departments should perfect the financing mechanism. The special funds encourage bank, energy-saving companies and other institution invest DR with a guarantee of a certain yield rate for the investors to improve their enthusiasm. Therefore the pressure of local governments can be relieved and help to enhance attraction of the financing.

## 3. Analysis on Influence of Factors for the Implementation of DR

It can be informed from the ISM model that there is certain

relationship among all the influence of factors for the implementation of DR. For a further understanding of the impact of influencing factors, it is necessary to arrange the weights of each factor in order. This paper used ANP to describe the relationship between objects accurately. However, the calculation progress of ANP is cumbersome and manual calculation is almost impossible. The software Super Decision (SD) as a powerful computing tool, can routinize the calculation. This paper using SD software for the calculation.

After consulting with relevant experts, the relationship among the influencing factors for the implementation of DR is determined and the ANP model for those factors with dependency relationships is established. In this structure, the control layer contains targets only, which is the influencing factors of DR Implementation barriers. The network layer consists of four factor groups influencing the implementation of DR. Capital factors ( $C_1$ ) include huge investment funds and long payback period ( $C_{11}$ ), sales price ( $C_{12}$ ), lack of long-term, effective financial support ( $C_{13}$ ); Institutional factors ( $C_2$ ) include Unsound regulatory mechanism ( $C_{21}$ ), lack of impetus for the market mechanism ( $C_{22}$ ), management and operation system are not substantial ( $C_{23}$ ), lack of energy-saving standard or access policies in some area ( $C_{24}$ ); External environment factors ( $C_3$ ) include lack of impetus for the market mechanism ( $C_{31}$ ), power surplus ( $C_{32}$ ), lack of incentive from grid companies ( $C_{33}$ ), lack of standardized energy saving service ( $C_{34}$ ); Promotion factors ( $C_4$ ) include lack of promotion ( $C_{41}$ ), lack of scientific awareness for the implementation ( $C_{42}$ ), lack of effective communication platform ( $C_{43}$ ). Input the index and their relationship into the SD software, so a network structure diagram is available, in which the ring arrows indicate there is interrelationship among indexes and the direct arrows indicate there is interrelationship among index sets.

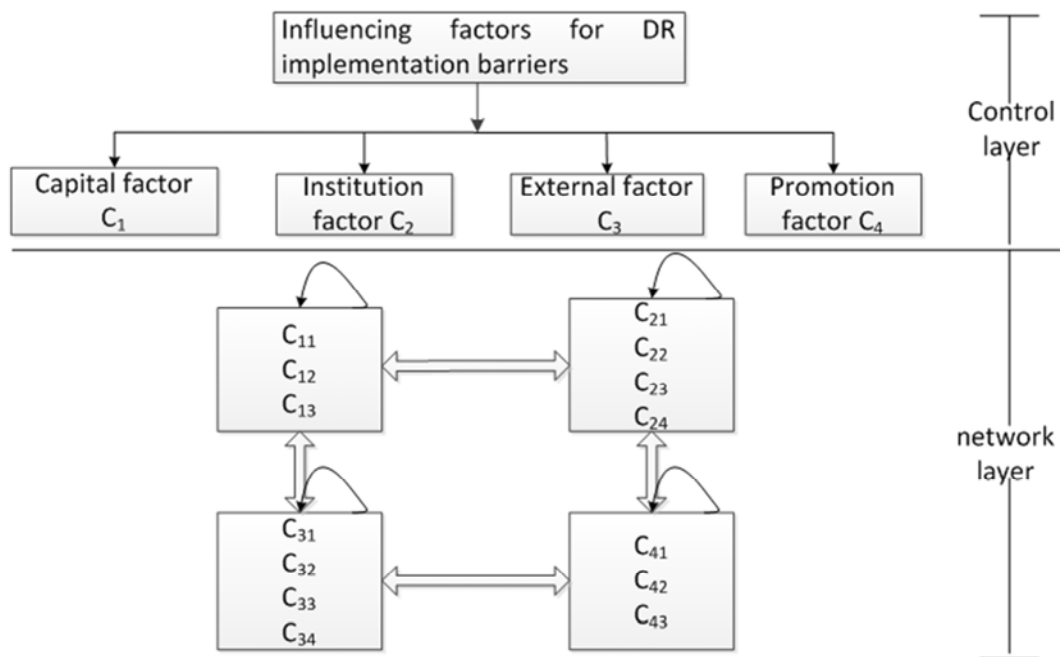


Figure 3. ANP model diagram of barrier factors for the implementation of DR.

### 3.1. Steps of ANP Method to Determine Weight

- (1) Construct ANP network model diagram. Analysis and represent the link between those indicators.
- (2) Construct ANP judgement matrix. Use 1-9 to score the factor collection in pairs and get the comparison matrix based on the advice from experts.
- (3) Calculate the relative weights of the factors based on the comparison. Then normalize the ordered super-matrix and the weighted super-matrix is available.
- (4) Calculate power limits of the weighted super-matrix and arrange them in comprehensive order. Then the

comprehensive weights of all the factors referring to the total goal are available and perform the consistency check.

### 3.2. Determination of Index Weight

Compare all the linked indicators with each other, if consistency ratio CR of the judgment matrix is less than 0.1, pass the consistency check. In the Super Decisions software, use 1-9 to score the judgment matrixes with a certain relationship in pairs based on the suggestions from experts and scholars, and the final weights of each influencing factor are shown in table 4.

Table 4. Comprehensive weight list of factors.

Serial Number	Factors	Weight	Serial Number	Factors	Weight
C <sub>11</sub>	Huge investment funds and long payback period	0.027	C <sub>31</sub>	Lack of impetus for the market mechanism	0.128
C <sub>12</sub>	Sales price	0.017	C <sub>32</sub>	Power surplus	0.046
C <sub>13</sub>	Lack of long-term and efficiency financial support	0.021	C <sub>33</sub>	Lack of incentive from grid companies	0.032
C <sub>21</sub>	Unsound regulatory mechanism	0.291	C <sub>34</sub>	Lack of standardized energy saving service	0.023
C <sub>22</sub>	There's no specific cost recovery approaches	0.134	C <sub>41</sub>	Lack of promotion	0.103
C <sub>23</sub>	Management and operation system are not substantial	0.064	C <sub>42</sub>	Lack of scientific awareness for the implementation	0.031
C <sub>24</sub>	There's no energy-saving standard or access policies in some area	0.040	C <sub>43</sub>	Lack of effective communication platform	0.041

Table 4 shows that the main barriers for implementation of DR include unsound regulatory mechanism, lack of specific cost recovery approaches, lack of impetus for the market mechanism, lack of promotion. Therefore, the relevant units should strengthen the management in these areas.

## 4. Conclusion

- (1) Based on the complex present situation and the character of DR implementation barriers, this paper proposed the index system for influencing factors of DR implementation barriers from four aspects including capital factor, institution factor, external condition and promotion. After reasoning and computing the relationship of all the factors with ISM, the multi-level structure of influencing factors of DR obstacle is available, which includes direct influencing factors on the surface, indirect influencing factors in the middle and fundamental factors deeply.
- (2) Among all the factors influencing the implementation of DR, the surface factors bring the most direct impact and the fastest improvement. Those factors include lack of long-term and effective financial support, lack of specific cost recovery approach, lack of substantial Management and operation system. Meanwhile, factors that bring the most fundamental, profound and lasting improvement include huge investment funds and long payback period, lack of effective communication platforms, and lack of impetus for the market mechanism. The multi-level hierarchical structure of all the factors established by ISM is helpful to form a

more intuitive and accurate understanding of each factor and provide a basis for further analysis of all the factors.

- (3) This paper used ANP method to determine the comprehensive influence weight of each influencing factor and drew the conclusion that the main barriers for the implementation of DR were unsound internal regulatory mechanism, lack of specific cost recovery approaches, lack of impetus for the market mechanism and lack of promotion. These analyze made further efforts to identify the key factors in the implementation of DR and provided reference for the policy-makers in the relevant departments.

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