Study and Implementation of Real Time Tariff for Residential Load in Other Countries and Proposing the Same for India

Archana S. Talhar, Sanjay B. Bodkhe

Abstract*: *The growth of any country depends on the availability, accessibility and affordability of electricity to all connected consumers; hence the electricity is the key for any developed country. To make electricity affordable and available to all consumers, many countries started implementing time based pricing to interested consumers. In India, energy tariff is slab wise for the residential load. The philosophy behind this slab wise tariff is to facilitate or reward low energy users and charge extra for high energy users. But in that case, the middle class group of society has no encouragement for optimal utilization of electricity. Therefore, in such circumstances the real time tariff is very much needed for residential consumers also. Some of the developed countries like Australia, United States (US), United Kingdom (UK), Europe, Japan, etc. are already implementing this concept. They have found that real time tariff is superior than slab wise tariff. In India, it has been a concern for economically poor class. A policy can be made for consumers below the poverty line or low income group; for them slab wise tariff will be continuing and for rest others, a provision of real time tariff can be made. Hence in this work proposing real time tariff for residential consumers in India. The existing tariff structure for India and other countries is discussed in this work and proposing the solution for the Indian residential sector.

Index Terms*: *Demand side management, Energy tariff, Mixed tariff, Real time tariff, Smart metering.

I. INTRODUCTION

Due to the modern lifestyle and advanced technologies, the electricity consumption in the residential sector increased dramatically. This leads to increase in electricity bills of residential consumers. During peak hours' massive demand of electricity but generation is not complying with the requirement. Hence, leading to higher generation costs during this period. Whereas during off peak hours the generation is same but the demand is less and hence energy gets wasted during this period. Therefore, there is always mismatch between the demand and supply of electricity. It clearly indicates that in the traditional power system, more attention is given to supply side compared to demand side. Consumers are assumed to be reluctant of actively changing their consumption pattern. To overcome this mismatch between demand and supply, demand side management need to find the aggressive solution.By recent developments on smart metering technologies in smart grid, several energy serving utilities have executed a diversity of time-based pricing programs. In the United States, Illinois Power Company is using a day-ahead real-time pricing (DA-RTP) tariff [2]; In California, Idaho, and New Jersey numerous pilot projects on critical peak pricing were executed [3]; In Ontario, Canada, a three-level (on-peak, mid-peak, off-peak) Time of Use (TOU) pricing tariff was implemented [4]. It is observed that by introducing consumers to hourly real-time prices is the most efficient tool which can request consumers to consume more cleverly and proficiently [5]. By taking advantage of lower energy prices in some periods and reducing electricity consumption when energy prices are high, RTP provides the opportunity to consumers to reduce their energy bills. In recent years, more attention is given to different types of pricing programs. A novel real-time pricing model based on smart metering and demand-side management is presented in [1] - [6]. The real time pricing is of many types like day ahead pricing, hourly ahead pricing, time of day pricing, critical peak period and critical peak rebate which is discussed in section 1.1 [7] – [10].

A. Real Time Pricing

1) Real Time Pricing (RTP): RTP is of two types. a) Day ahead pricing b) Hourly ahead pricing. In Day ahead pricing, the consumer knows the cost of electricity for the next day in advance. In hourly ahead pricing, the rates change over an hour and the consumer receives the signal for each interval, indicating the costs of generating electricity during that period.
2) Time of Day (ToD): In time of day, entire day is divided into two or three large intervals with different prices. The intervals can be divided as off-peak period (lowest rate), shoulder period (moderate rate) and peak period (highest rate); these rates remain fixed day-to-day over the seasons i.e. summer, winter & rainy.
3) Critical Peak Period (CPP): Consumer receives a message through email, SMS, or the phone call, suggesting them that the price of electricity will increase dramatically in the next day or even in the coming hours. The consumer can avoid paying high prices by reducing electricity use during these periods of high demand.

Revised Manuscript Received on March 04, 2019.

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4) Critical Peak Rebate (CPR): The utility pays the consumer for each kilowatt hour of electricity they are able to reduce relative to the amount they normally use during critical peak times.

B. Real Time Pricing in Other Countries

The growth of any country depends on electricity access to all consumers. Therefore, many developed countries like Australia, United States (US), United Kingdom (UK), Europe, Japan, etc. have started offering time base pricing to all consumers. The utility company like Commonwealth Edison (ComEd), Ameren Illinois Utilities, Oklahoma Gas & Electric (OG&E), Sacramento Municipal Utility and Arizona Public Service (SMUD) are offering these demand response systems to interested customers [11] – [14].

1) Ameren Illinois utilities

Ameren Illinois Utility have a goal of delivering safe, reliable and affordable energy to the consumers. To optimize the electricity usage, many energy efficiency programs with tips, tools and incentives are offered to consumers. It offers real-time pricing options that allow all customers access to variable hourly prices for power. Based on the market supply and demand, real time prices fluctuate. Normally, during the summer months i.e. from June to September and daily during peak demand hours i.e. from 5 am to 9 pm, market prices are highest. By referring price signals available through RTP, the consumer can schedule their energy usage and can potentially save money when compared to the standard rate. RTP customers are motivated to check day-ahead prices. It does not profit from electric supply charges, including those for real-time pricing. They pass along the price they pay for electricity to their consumers, dollar for dollar.

The Fig. 1. Shows the real time hourly pricing of the Ameren Illinois utility for September 20th 2018 [15]. The price of electricity is in cent per kW which varies throughout the day. It is observed that approximately from 2:00 pm to 7:00 pm, the price of electricity is high as compared to the other period of the day. So this period of the highest cost is called as peak period.

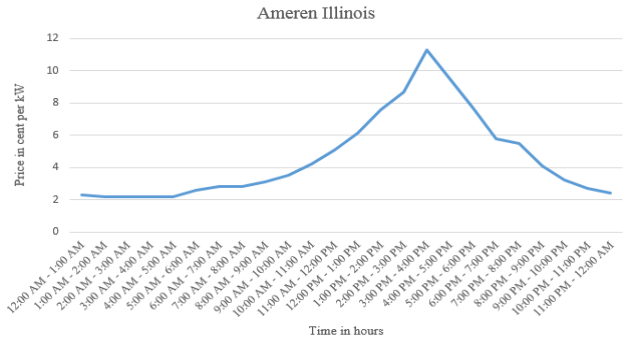

Fig. 1: Hourly pricing of Ameren Illinois on September 20th, 2018.

2) Commonwealth Edison (ComEd)

Commonwealth Edison, commonly known as ComEd, is the biggest electric utility in Illinois. It has a monopoly in Northern Illinois and Chicago. It serves in Iroquois County to the south, the Wisconsin border to the north, the Iowa border to the west, and the Indiana border to the east. Headquarters are located in Chicago, Illinois, United States. Normally hot summer afternoons are considered as the most important time to shift usage. During the fall, winter and spring, prices on ComEd's hourly pricing program typically remain low, but can spike due to extreme weather conditions. It broadcast three prices to help the consumer in tracking hourly prices: The real-time hourly market price, the current hour average price, and the day-ahead hourly market price. The Fig. 2. Shows the day ahead hourly pricing and real time hourly pricing of the same utility for the September 21st 2018 [16]. The blue colour line shows the day ahead pricing and the orange colour line shows the real time pricing. It is observed that in day ahead pricing, the rate of electricity is highest approximately during the time interval 2:00 pm to 7:00 pm (peak period).

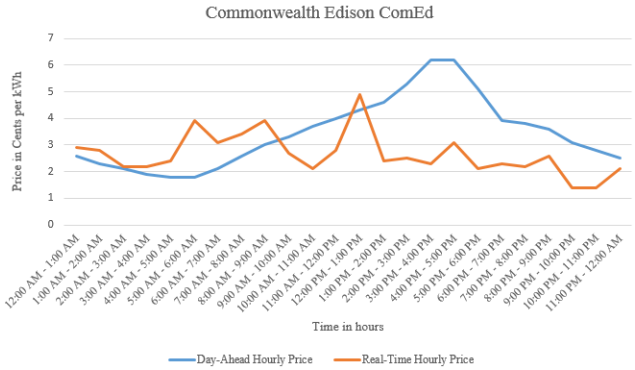

Fig. 2: Day ahead & real time pricing on September 21st, 2018.

3) Oklahoma Gas & Electric (OG&E)

The aim of Oklahoma Gas and Electric (OG&E) is to provide safe and reliable electricity to their communities at a reasonable cost. The headquarter of OGE Energy Corporation is located in Oklahoma City. It is publicly traded on the New York Stock Exchange under the symbol OGE. It is the parent company of Oklahoma Gas and Electric (OG&E), a regulated utility. The Fig. 3. shows the day ahead hourly pricing and real time hourly pricing of the same utility for the September 20th 2018 [17]. The price of electricity is in cent per kW which varies in a day for two pricing intervals i.e. peak period from 2:00 pm to 7:00 pm and off peak period, which is time other than peak period.

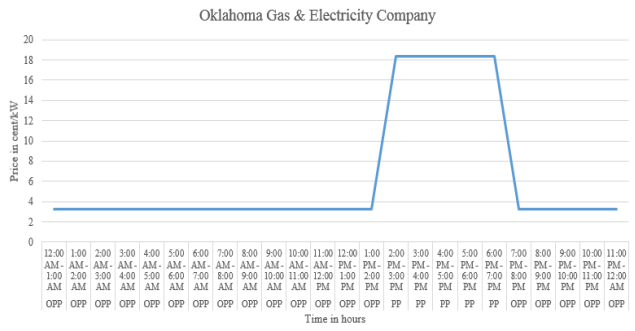

Fig. 3: Time of use pricing on September 20th, 2018.

4) Sacramento Municipal Utility and Arizona Public Service (SMUD)

SMUD began serving Sacramento in 1946 and is now the nation's sixth-largest community-owned electric utility. SMUD provides reliable, affordable electricity to most of the Sacramento County and a portion of Placer County. SMUD is recognized nationally and internationally for its innovative energy efficiency programs and renewable power technologies, SMUD was the first large California utility to receive more than 20 percent of its energy from renewable resources. The SMUD offers time of day to its consumers. On the Time-of-Day Rate, consumer pay different rates for electricity based on the season and the time of day that they use it. Rates are lower during off-peak periods because it costs utility less to produce or purchase electricity. The rates increase as demand and cost for electricity increase, especially during the summer months. ToD rates help consumer to control electric bill when they: a) Shift electricity use to lower-cost off-peak times b) Use less electricity during the 5:00 pm to 8:00 pm. peak hours and c) Reduce their overall usage.

The Fig. 4. shows the time of day pricing for SMUD utility [18]. This ToD structure is different for the summer season (June 1 to September 30) and Non-summer season (October 1 to May 31). During the non-summer season, the time period is divided into two intervals like peak and off peak period. From midnight to 5:00 pm & 8:00 pm to midnight is off peak period. From 5:00 pm to 8:00 pm is peak period. Rates are different for both the periods.

During the summer season, the time period is divided into three intervals like peak, off peak and mid peak. From midnight to noon is off peak period; noon to 5:00 pm & 8:00 pm to midnight is mid peak period and from 5:00 pm to 8:00 pm is peak period. Charges are different for each interval.

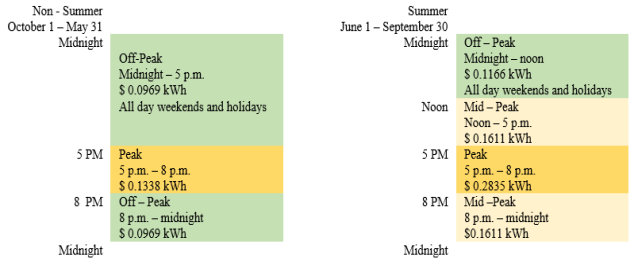

Fig. 4: Time – of – Day structure of SMUD.

II. EXISTING TARIFF STRUCTURE IN INDIA (MAHARASHTRA STATE) FOR THE RESIDENTIAL LOAD

The power system in Maharashtra is divided into two parts: Mumbai which is the capital of India is served by Reliance energy, TATA power, BEST undertaking and rest of Maharashtra is served by the Maharashtra State Electricity Distribution Company Limited (MSEDCL) [19]. The tariff structure is almost same for all utilities supplying electricity. The slab wise tariff is available for residential sector and time - of - day is available for non-residential sector. The existing tariff structure for residential sector is shown in Table 1 particularly for the utility MSEDCL [20].

Table 1: Existing Tariff Structure for Residential Load

Consumption Slab kWh	Fixed/Demand Charges (Rs. / month)	Wheeling Charges (Rs. / kWh)	Energy Charges (Rs. / kWh)
0 – 100	1- Phase: Rs.65/ month	1.18	3.07
101 – 300		1.18	6.81
301 – 500		1.18	9.76
500 – 1000	3- Phase: Rs.185/ month	1.18	11.25
Above 1000		1.18	12.53

Table 2: Existing Tariff Structure for the Non-Residential Load

TOD Tariffs (in addition to Base Tariff & charges) for Non- Residential sector		
TOD		**Energy Charges (Rs. /kWh)**
2200-0600 Hrs	Off peak period (OPP)	-1.50 (Rebate)
0600-0900 Hrs & 1200-1800 Hrs	Shoulder period (SP)	0.00 (Base rate)
0900-1200 Hrs	Morning Peak (MP)	+ 0.80 (Penalty)
1800-2200 Hrs	Evening Peak (EP)	+ 1.10 (Penalty)

Table 2. shows the time of day structure of non - residential sector which is on an above the base charges (additional charges). This time of the day is divided into four intervals. To understand the effect of the time period on energy charges, author assumes the names of the period as off peak period (OPP), shoulder period (SP), morning peak (MP) and evening peak (EP). The details of the periods are as follows:

a) Off peak period (OPP): Time allotted for off peak period is 2200 - 0600 Hrs. If the consumer uses energy during this period, consumer will get a rebate of -1.5 Rs/kWh in addition to base charges. i.e. the amount per unit is going to decrease which is the most golden period for the consumer to save the electricity bill.

b) Shoulder period (SP): Time allotted for shoulder period is 0600 - 0900 Hrs and 1200 - 1800 Hrs. If the consumer uses energy during this period, then the consumer has to pay only base charges. Need not to pay any extra charges above base charges. i.e. this is a no loss no gain period.

c) Morning Peak (MP): Time allotted for the morning peak period is 0900 - 1200 Hrs. If the consumer uses energy during this period, then the consumer has to pay + 0.8 Rs/kWh charges in addition to base charges. This period is also referred as the penalty period.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

d) Evening peak (EP): Time allotted for evening peak period is 1800 - 2200 Hrs. If the consumer uses energy during this period, then the consumer has to pay + 1.10 Rs/kWh charges in addition to base charges. This period is also referred as the highest penalty period. During this period, the charges of energy is highest as compared to other periods.

According to the existing tariff structure of residential sector as shown in Table 1, the per unit electricity charge is calculated as: Fixed charges for the single phase is 65 Rs. / month and if the consumer consumes 300 units in a month then the fixed charges will be 65/300 = 0.216 Rs/unit. For the three phase supply it is 185/ 300 = 0.616 Rs/unit. Fixed charges includes the cost of installation, maintaining meters, meter reading, systems for billing, customer service and complaints etc. Generation plants are located at remote area and utility need to transmit power over long distances. This work of transmission is done by transmission company. The Distribution company has to pay the transportation charges to the transmission company. These charges are known as Wheeling Charges. Wheeling charges per unit consumption is almost constant i.e. 1.18 Rs for all slabs in this case. Also energy charges are applicable according to the number of unit's consumption slab wise. The calculation of base charges per unit consumption for single phase and three phase residential load is shown in Table 3 for all slabs.

Table 3: Calculation of Base Electricity Charges

Slab in Units	Per unit wheeling charges in Rs. (1)	Per unit energy charges in Rs. (2)	Per unit fixed charge (1-ph) in Rs. (3)	Per unit fixed charge (3-ph) in Rs. (4)	Base charges Rs. /unit (1-ph) (5) = (1+2+3)	Base charges Rs. /unit (3-ph) (6) = (1+2+4)
0 – 100	1.18	3.07	0.65	1.85	4.90	6.10
101 – 300	1.18	6.81	0.216	0.616	8.206	8.606
301 – 500	1.18	9.76	0.13	0.37	11.07	11.31
500 – 1000	1.18	11.25	0.065	0.185	12.495	12.615
Above 1000	1.18	12.53	0.065	0.185	13.775	13.895

III. THE PROPOSED TARIFF STRUCTURE FOR INDIAN RESIDENTIAL LOAD (MAHARASHTRA STATE)

If time - of - day (ToD) for non-residential sector is applied to residential sector, then according to ToD, energy charges will vary. If the residential consumer is using energy during peak hours, then the consumer need to pay additional charges on above the base charges. According to ToD, during the shoulder period consumer will pay only base charges and during the off peak period consumer will get rebate and amount get subtracted from base price. Table 4 is showing the effect of ToD on per unit energy consumption rate with respect to residential load.

Table 4: Effect of TOD on Per Unit Energy Consumption

Consumption Slab kWh (residential)	Electricity charges Rs. /unit (1-ph)	Electricity charges Rs. /unit (3-ph)
0 – 100	4.90	6.10
101 – 300	8.206 (Base charge)	8.606 (Base charge)
MP (+ 0.8)	MP = 9	MP = 9.4
EP (+ 1.1)	EP = 9.3	EP = 9.7
OPP (- 1.5)	OPP = 6.706	OPP = 7.1
SP (+ 0)	SP = 8.206	SP = 8.606
301 – 500	11.07 (Base charge)	11.31 (Base charge)
MP (+ 0.8)	MP = 11.87	MP = 12.11
EP (+ 1.1)	EP = 12.17	EP = 12.41
OPP (- 1.5)	OPP = 9.57	OPP = 9.81
SP (+ 0)	SP = 11.07	SP = 11.31
500 – 1000	12.495 (Base charge)	12.615 (Base charge)
MP (+ 0.8)	MP = 13.29	MP = 13.41
EP (+ 1.1)	EP = 13.59	EP = 13.71
OPP (- 1.5)	OPP = 10.99	OPP = 11.11
SP (+ 0)	SP = 12.495	SP = 12.615
Above 1000	13.775 (Base charge)	13.895 (Base charge)
MP (+ 0.8)	MP = 14.575	MP = 14.695
EP (+ 1.1)	EP = 14.875	EP = 14.995
OPP (- 1.5)	OPP = 12.275	OPP = 12.395
SP (+ 0)	SP = 13.775	SP = 13.895

The author proposes a flat rate tariff for low energy users (0-100 units) and Time of Day for high energy users (from 101 units to Above 1000 Units). Then, depending upon the number of unit's consumption and the time period at which units are consumed, the real time tariff will be applicable as shown in Table 4.

For example, if the monthly unit consumption of residential consumer having 1-phase supply is say 100 units then flat rate charges will be applicable i.e. 4.90 Rs. / unit as shown in Table 4. If the monthly consumption of a 1- phase consumer is say 300 units then base charge will be 8.206 Rs. / unit. Now if the consumer is using energy in morning peak hours then according to ToD, charges will be 9 Rs. / unit; if using in evening peak hours then charges will be 9.3 Rs. / unit; if using in off peak hours then charges will be 6.706 Rs. / unit; and if using in shoulder hours then charges will be 8.206 Rs. / unit. The same concept is applicable for all slabs to single phase and three phase supply. To optimize the electricity bill, if consumer schedules load during the shoulder period, then the consumer has to pay only the base charges. If the consumer schedules load during the off peak period, then the consumer is getting the rebate of -1.5 Rs. / kWh; thereby resulting into the higher saving of electricity bill as compared to other period. As per above discussion, if we combine the slab wise tariff of residential sector with time of day tariff of non-residential sector, then the cost of electricity will reduce and the consumer will get a choice of using appliances on different time periods. Depending on the time period at which the consumers are using electricity, the bill will get optimized.

The existing tariff structure of residential load (slab wise) in Maharashtra state is shown in Table 5.

Table 5: Existing Tariff Structure

Consumption Slab	Consumption in kWh	Tariff Structure
Slab 1	0 – 100 kWh	
Slab 2	101 – 300 kWh	
Slab 3	301 – 500 kWh	Slab wise flat rate tariff
Slab 4	500 – 1000 kWh	
Slab 5	Above 1000 kWh	

The proposed tariff structure is shown in Table 6, 7 and 8. Here, the slab wise tariff of residential load is combined with real time tariff of non - residential load and a novel concept of mix tariff is proposed to optimize electricity bills. Table 6 shows the proposed tariff structure 1.

Table 6: Proposed Tariff Structure 1

Consumption Slab	Consumption in kWh	Tariff Structure
Slab 1	0 – 100 kWh	Flat rate tariff
Slab 2	101 – 300 kWh	Peak Period (PP) Shoulder Period (SP) Off Peak Period (OPP)
Slab 3	301 – 500 kWh	Peak Period (PP) Shoulder Period (SP) Off Peak Period (OPP)
Slab 4	500 – 1000 kWh	Peak Period (PP) Shoulder Period (SP) Off Peak Period (OPP)
Slab 5	Above 1000 kWh	Peak Period (PP) Shoulder Period (SP) Off Peak Period (OPP)

In the existing tariff structure, there are five slabs. So in the proposed tariff structure 1, for the first slab i.e. 0-100 kWh, the flat rate tariff will be applicable and for rest other slabs like 101-300 kWh, 301-500 kWh, 500-1000 kWh and above 1000 kWh, real time tariff will be applicable. Depending upon the time period of unit consumption, each slab will be again divided into three parts like peak period (PP), shoulder period (SP) and off peak period (OPP) and accordingly the per unit charges will be applicable.

Table 7: Proposed Tariff Structure 2

Consumption Slab	Consumption in kWh	Tariff Structure
Slab 1	0 – 100 kWh	Flat rate tariff
Slab 2	101 – 300 kWh 301 – 500 kWh 500 – 1000 kWh Above 1000 kWh	Peak Period (PP) Shoulder Period (SP) Off Peak Period (OPP)

The proposed tariff structure 2 is shown in Table 7. According to this proposed tariff structure, only two slabs will be made available for consumers. Slab 1 will be from 0-100 kWh and slab 2 will be from 101-Above 1000 kWh. For slab 1, the flat rate will be continuing and for slab 2, real time tariff will be applicable. The time of the day will be divided into three intervals like peak period (PP), shoulder period (SP) and off peak period (OPP).

The proposed tariff structure 3 is shown in Table 8. According to this proposed tariff structure, only one slab will be made available for all consumers. This slab will be from 0 – above 1000 kWh. Only real time tariff will be applicable for this slab. The time of the day will be divided into three intervals as similar to proposed tariff structure 1 and 2.

Table 8: Proposed Tariff Structure 3

Consumption Slab	Consumption in kWh	Tariff Structure
Only real time tariff	0 – 100 kWh 101 – 300 kWh 301 – 500 kWh 500 – 1000 kWh Above 1000 kWh	Peak Period (PP) Shoulder Period (SP) Off Peak Period (OPP)

IV. CONCLUSION

In the existing flat rate tariff structure for residential load in Maharashtra state (India), there is no provision for consumer to plan or schedule their electricity consumption pattern. Therefore, a novel concept of the mix tariff structure for residential load is proposed in this work. This mix tariff structure will have the provision of scheduling the load as time of day (ToD) prices are fixed for each time period and it will be same for all the seasons. These charges will be known to consumers in advance; so it will help in designing the load pattern for optimizing electricity bills. Table 5 shows the existing tariff structure for residential load.

Table 6, 7 and 8 shows the proposed concept of mix tariff. In the existing slab wise tariff, we can have an embedded time of day (ToD) structure. Depending upon the units' consumption, falling into the respective slabs, per unit cost of electricity will vary according to the real time tariff. So, if the consumer is utilizing energy during off peak hours or shoulder hours then he has to pay fewer charges as compared to morning / evening peak hours as shown in Table 4. Hence, now the consumer will have a choice of selecting an appropriate time period for optimizing the cost of electricity.

Implementation of the proposed ToD tariff for residential sector in India will be beneficial to the consumers, utilities as well as to the society. Reduction in maximum load during peak hours will decrease the demand of enhancing generation capacities and help overcome power congestion to some extent. The social response towards energy conservation will be rewarded by reduced energy bills. Reduction in greenhouse gases will be an added advantage. The proposed tariff structure can be further substantiated by detailed analysis of electricity pricing considering various practical aspects and factors involved therein.

ACKNOWLEDGMENT

Authors are grateful to the Management and Dr. B. K. Mishra, Principal, Dr. Sandhya Save, H.O.D. Electronics of Thakur College of Engineering and Technology, Mumbai, India for their support. Also grateful to Dr. Sangeeta Mishra, friends and family members, who have supported us along the way.

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