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Time of use electricity pricing in power system planning and operation: Case study of Nepalese power system

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Abstract

The difference between load demand in the off-peak and peak period is usually high in the context of Nepal, and the high peak load for a short time is the main reason for insufficiency in electricity, frequent electricity outage, and poor power quality. This paper investigates the effectiveness of the time of use (TOU) strategy to reduce peak demand and to improve power quality. TOU electricity price is one of the electric demand response (DR) strategies, which may motivate the customers to reduce their consumption in peak periods and shift load in the off-peak period, which propel the electricity industry towards a higher efficiency compared to that of common flat prices. In this paper, a process based on an equal step length iteration algorithm is used to obtain an optimal period partition. Using the particle swarm optimization (PSO) algorithm, a TOU-based optimization model is proposed to find the optimal electricity price. Then, its impact on peak demand reduction and voltage fluctuation is analyzed. The impact of TOU price on peak demand reduction is investigated in the hourly load profile of Nepal, which indicates the significant reduction in peak demand. Similarly, the impact on voltage fluctuation is analyzed through a case study of the IEEE 33-bus radial distribution test system, which shows voltage profile is improved.

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Keywords: Equal step length iteration algorithm; Particle swarm optimization; IEEE 33-bus radial distribution test system; Peak demand; Power quality

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1. Introduction

In the context of Nepal, the gap between load demand during off-peak and peak periods is typically large, and high peak load for a short time is the primary cause of electricity insufficiency, regular power outages, low reliability, and poor power quality. During the peak period, there is significant pressure for the utility to supply electricity to

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the consumers, and reversely even a very small generation is enough to provide sufficient electricity to meet the consumer demand during off-peak. Due to the high peak demand, there is a need for an extra power plant for the short time due to which the system is unreliable and uneconomic.

In Nepal, no such study has been reported which introduced the time of use (TOU) electricity price to reduce peak demand and to improve power quality. The time of use (TOU) as one of the demand response strategies has been widely used in the electrical power system. The demand response (DR) program has a significant influence on improving the power system performances [1–3]. According to the U.S. Department of Energy (DOE) [4,5] DR is defined as "changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized". As a price-based DR, TOU has been applied by many utility companies as an approach to reduce the demand during the peak-time and to improve the utilization efficiency of power grids [6].

TOU is a rate that has varying unit values over various blocks of time, normally a 24-h day. The total cost of generating and distributing electricity over those cycles is reflected in TOU prices. TOU values are usually pre-determined for several months or years and differ by time of day (e.g., peak vs. off-peak period) and season. TOU rates are widely used by residential, commercial, and industrial users, and they necessitate meters that monitor accumulated use over several periods. Customers with TOU tariffs get time-varying prices that represent the demand and cost of electricity at various times. Customers that have this knowledge prefer to use less energy during periods when electricity costs are high. This paper contributes to the utility company of Nepal to implement TOU price and also it helps for further study of TOU pricing in Nepalese power system. The rest of this paper is grouped as follows. Section 2 describes the overall methodology used in this study. Section 3 presents the results obtained from the study. Section 4 summarizes the paper.

2. Methodology

To analyze the impact of TOU electricity pricing in the Nepalese power system, the methodology is divided into three parts. In the first part of the methodology, the peak-flat-valley period partitioning process is proposed based on an equal step length iteration algorithm to divide a daily load curve into three periods that are peak period, flat period, and valley period. In the second part, the process based on particle swarm optimization algorithm is proposed to optimize the time of use electricity price. Lastly, the price elasticity demand technique is used for the calculation of electricity demand for each period by applying the TOU price. After calculating the total electricity demand of each period, to find out sequential hourly load data an average apportionment method is used. Each of the proposed processes is explained as follows:

2.1. Peak-flat-valley period partition

For the peak-flat-valley period partition, there are different methods like k-means clustering algorithm, PSO based optimization algorithm but in this paper, a process based on equal step length is used due to its more effective than the conventional k-means clustering algorithm and PSO based optimization algorithm [7].

The proposed process starts with the input of hourly sequential load data of consumers. An objective function is considered to optimize the partition problem which is presented in Eq. (1) [7]. The objective function is calculated iteratively up to a specified iteration. In each iteration, the load curve is divided into three periods. The partition that has the minimum value of an objective function is the optimal peak-flat-valley period partition.

$$Min\,RMSD = \sqrt{\frac{1}{24}\sum_{t=1}^{24}\left(L_t - \sum_{j=1}^{3}\theta_j v_j | L_t \in S_j\right)^2} \tag{1}$$

2.2. Time of use price optimization

In the context of Nepal, the most used electricity price structure is the block rate tariff. To date, the impact of TOU on peak demand reduction is not studied so this paper mainly focused on peak load reduction and minimization of peak–valley load difference. To minimize peak load and peak–valley difference, two objective functions are constructed [8], and given by Eqs. (2) and (3).

$$F_1 = \min\left\{\frac{L_{\max}^{afterTOU}}{L_{\max}^{beforeTOU}}\right\} \tag{2}$$

$$F_2 = \min\left\{\frac{L_{\max}^{afterTOU} - L_{\min}^{afterTOU}}{L_{\max}^{beforeTOU} - L_{\min}^{beforeTOU}}\right\} \tag{3}$$

Where $L_{\max}^{beforeTOU}$ and $L_{\min}^{beforeTOU}$ are peak load demand and valley load demand before the application time of use electricity price respectively $L_{\max}^{afterTOU}$ and $L_{\min}^{afterTOU}$ are peak load demand and valley load demand after the application time of use electricity price respectively. This paper mainly focused on peak load minimization and peak–valley difference minimization so two constraints are defined for an optimization problem. The first constraint is related to the price of different periods and the second constraint is related to load difference between peak and valley periods, which are as follows:

$$C_1 = M_p - M_f > 0 \tag{4}$$

$$C_2 = M_f - M_v > 0 \tag{5}$$

$$C_3 = L_{p\min} - L_{v\max} > 0 \tag{6}$$

Where, M_p, M_f and M_v are price at peak, flat and valley period respectively. Similarly, $L_{p\min}$ and $L_{v\max}$ are minimum load in the peak period and the maximum load in valley period after TOU price, respectively. The particle swarm optimization (PSO) algorithm can be used in different power system optimization problems [9]. A process based on particle swarm optimization (PSO) algorithm is proposed to optimize the time of use electricity price. A flowchart for the proposed process is shown in Fig. 1.

2.3. Hourly load calculation after the application of TOU

Total energy consumption for each period after application of TOU price is calculated by the price elasticity of demand technique [10,11]. The detailed data of the elasticity matrix can be found in [12]. Then an apportionment technique is used to obtain hourly load after application of TOU [13]. The price elasticity matrix of demand is given by Eq. (7), and the hourly load calculation after the application of TOU is done by using Eq. (8).

$$\begin{bmatrix} \dfrac{\Delta E_p}{E_p} \\ \dfrac{\Delta E_f}{E_f} \\ \dfrac{\Delta E_v}{E_v} \end{bmatrix} = \begin{bmatrix} \lambda_{pp} & \lambda_{pf} & \lambda_{pv} \\ \lambda_{fp} & \lambda_{ff} & \lambda_{fv} \\ \lambda_{vp} & \lambda_{vf} & \lambda_{vv} \end{bmatrix} \begin{bmatrix} \dfrac{\Delta M_p}{M_p} \\ \dfrac{\Delta M_f}{M_f} \\ \dfrac{\Delta M_v}{M_v} \end{bmatrix} \tag{7}$$

$$L_i'(m) = L_i\left(1 + \sum_{j=1}^{3} \lambda_{ij}\frac{m_j - m_o}{m_o}\right)(i \in S_l = 1, 2, 3) \tag{8}$$

2.4. Impact analysis

2.4.1. Load factor

After implementing the TOU strategy, the energy consumption pattern of the consumer should be analyzed. For the analysis of the energy consumption, the Load Factor (LF) is defined as the comparison factor. Load Factor is defined as the ratio of the average energy consumption at a certain period to the maximum energy that could have been consumed at the same period. Mathematically, the relation of Load Factor and Daily Load Factor can be shown in Eqs. (9) and (10).

$$Load\ Factor = \frac{Average\ Energy\ Consumption}{Maximum\ Energy\ Consumption} \tag{9}$$

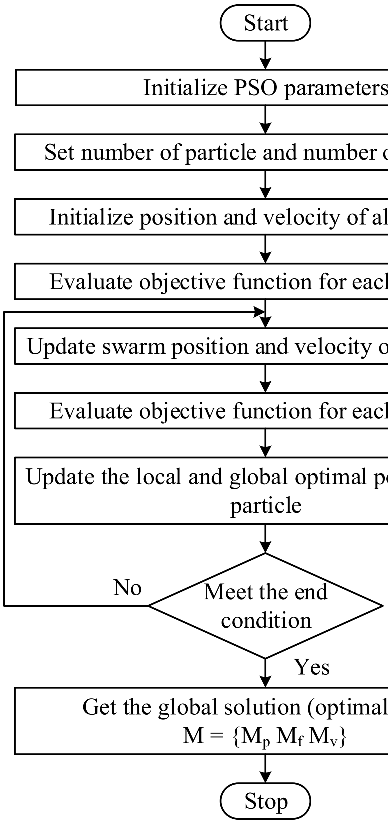

Fig. 1. Flowchart of PSO based TOU price optimization.

$$Daily\ Load\ Factor = \frac{Actual\ Energy\ Consumption\ in\ 24\ \text{hour}}{Maximum\ Energy\ that\ can\ be\ consumed\ in\ that\ period} \tag{10}$$

2.4.2. Node voltage

For the analysis of node voltage profile load flow analysis is performed. The forward and backward sweep algorithm [14] is used for load flow analysis due to the radial distribution system as a case study.

3. Result and discussion

In this paper, the Nepalese power system and IEEE-33 radial distribution test system are taken as a case study. Impact on peak demand reduction and peak–valley difference minimization is thoroughly studied in the Nepalese power system data and impact on node voltage and power loss is studied in IEEE-33 radial distribution test system.

3.1. Peak-flat-valley period partition

For the optimal peak-flat-valley period partition a process based on an equal step length iteration algorithm is used. Secondary data of the Integrated Nepal Power System (INPS) [15], is taken as the sequential load data for optimal PFV period partition. 7th January, 23rd April, and 12th September are assumed as typical days for analysis which covers different seasons in a year. The peak value is assumed as a base value. The result obtained from the period partition for January, April, and September are presented in Fig. 2(a), 2(b), and 2(c) respectively.

From Fig. 2, it can be observed that, in January, the peak period falls between 18:00–20:00, the flat period falls between 6:30–11:00, 17:30 and 20:30–21:00, and the valley period falls between 1:00–6:00, 12:00–17:00, and 22:00–24:00. In the month of April, the peak period falls between 18:30–22:00, the flat period falls between 7:00–8:00, 11:00–14:00, and 18:00, and the valley period falls between 1:00–6:30, 10:00, 16:00, 17:00–18:00 and

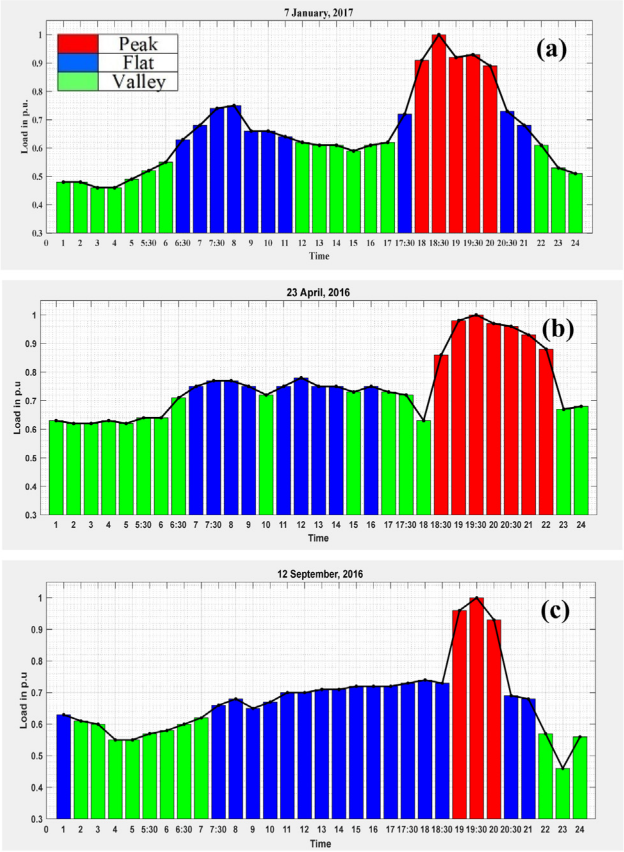

Fig. 2. PFV periods for the months of (a) Jan, (b) April, (c) Sep.

23:00–24:00. In September, the peak period includes the time between 19:00–20:00, the flat period includes the time between 7:30–18:00, 20:30–21, and 1:00, and the valley period includes the time between 2:00–7:00, 22:00–24:00.

3.2. Time of use price optimization

The PSO-based process is proposed to optimize the TOU price. Before the application of TOU, the original block rate price is 0.0757 USD as of October 30, 2020. The peak-flat-valley period price obtained from PSO optimization is presented in Table 1. It is assumed that the same price for all three sample days is taken as typical days in the paper.

Table 1. Results of TOU price from PSO optimization.

Period	January	April	September
Peak period	0.1215	0.1215	0.1215
Flat period	0.0718	0.0718	0.0718
Valley period	0.0421	0.0421	0.0421

3.3. Impact analysis

After TOU price optimization, its impact on load profile for the months January, April, and September is observed which are shown in Figs. 3(a), 3(b), and 3(c) respectively. Peak load before and after the application of TOU is presented in Table 2. From Table 2 it can be observed that in the months January, April, and September peak

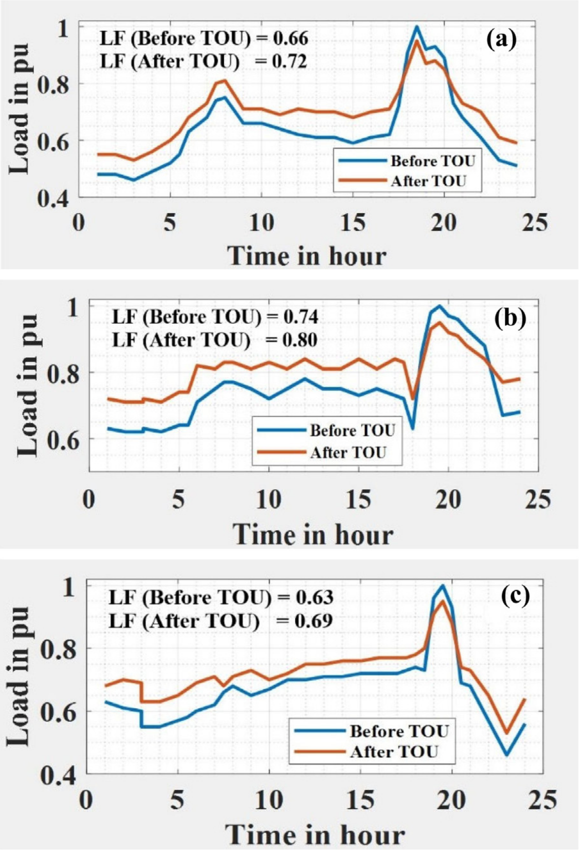

Fig. 3. Load profile for the months of (a) Jan, (b) April, (c) Sep before and after the application of TOU.

Table 2. Peak Load comparison before and after TOU price.

Peak load (MW)	January	April	September
Before TOU	1381.5	1271.34	1372.9
After TOU	1312.42	1207.77	1304.25
Difference	69.08	63.65	68.65

demand is decreased by 69.08 MW, 63.65 MW, and 68.65 MW respectively. From Figs. 3(a), 3(b), and 3(c) it can be seen that the load profile after TOU becomes flat than before TOU. Also, the load factor after TOU is improved in all three cases.

3.4. Impact on node voltage

The impact on node voltage and active power loss is analyzed in the IEEE 33-bus radial distribution test system and its detailed data can be found in [16]. The node voltage before and after TOU price is shown in Fig. 4 where it can be observed that the voltage profile is improved after the implementation TOU price. Before TOU price at nodes 13 to 18 voltage is below the limit i.e. less than 0.95 pu (assuming ±5% voltage limit) but after TOU voltage profile at that nodes is improved to limit.

4. Conclusion

In this paper, the impact of TOU electricity price is investigated for the Nepalese power system. The result shows that the peak demand can be reduced by shifting the load to the valley period and the Load Factor can be improved

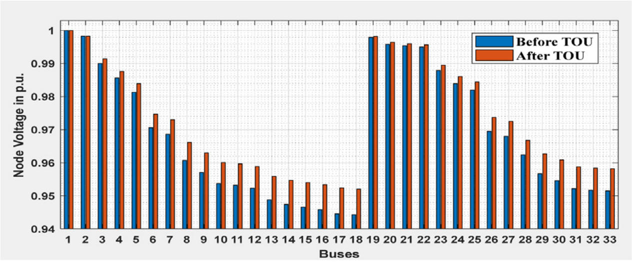

Fig. 4. Voltage profile before and after the application of TOU.

after the application of TOU price. Reduction in peak demand enhances the reliability of the overall power system, and the energy insufficiency problem can be solved during the peak period. Higher the Load Factor after TOU price signifies proper utilization of electrical energy, economizes the electricity cost per unit energy generated, and consumers will be benefitted. Reduction in peak demand reduces the investment cost in new power plants to meet the energy demand. Also, after the application of TOU peak–valley, the difference between generation and demand is reduced which results in less load fluctuation. Less load fluctuation improves the voltage profile of the system which improves the power quality. Therefore, this study has great importance in the Nepalese power system on improving reliability, power quality, and economic benefits.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Cheng J, Chu F, Zhou M. An improved model for parallel machine scheduling under time-of-use electricity price. IEEE Trans Autom Sci Eng 2018;15(2):896–9. http://dx.doi.org/10.1109/TASE.2016.2631491.

[2] Zhao L, Yang Z, Lee WJ. The impact of time-of-use (TOU) rate structure on consumption patterns of the residential customers. IEEE Trans Ind Appl 2017;53(6):5130–8. http://dx.doi.org/10.1109/TIA.2017.2734039.

[3] Hung YC, Michailidis G. Modeling and optimization of time-of-use electricity pricing systems. IEEE Trans Smart Grid 2019;10(4):4116–27. http://dx.doi.org/10.1109/TSG.2018.2850326.

[4] Organized O, The BY, De O, The OF. C Ontracts in E Lectricity M Arkets, No. February. 2009, p. 13–4.

[5] Mohsenzadeh A, Kapourchali MH, Pang C, Aravinthan V. Impact of smart home management strategies on expected lifetime of transformer. In: Proc. IEEE power eng. soc. transm. distrib. conf. 2016-july. 2016, http://dx.doi.org/10.1109/TDC.2016.7519945.

[6] Neenan B, Eom J. Price elasticity of demand for electricity: a primer and synthesis. Electr Power Res Inst 2008.

[7] Yang H, Wang L, Zhang Y, Tai H, Member S. Reliability evaluation of power system considering time of use electricity pricing. IEEE Trans Power Syst 2018;PP(c):1. http://dx.doi.org/10.1109/TPWRS.2018.2879953.

[8] Yang H, Wang L, Ma Y. Optimal time of use electricity pricing model and its application to electrical distribution system. IEEE Access 2019;7:123558–68. http://dx.doi.org/10.1109/access.2019.2938415.

[9] Pornsing C, Watanasungsuit A. Discrete particle swarm optimization for disassembly sequence planning. In: ICMIT 2014-2014 IEEE int. conf. manag. innov. technol. 2014, p. 480–5. http://dx.doi.org/10.1109/ICMIT.2014.6942474.

[10] Kirschen DS, Strbac G, Cumperayot P, De Mendes DP. Factoring the elasticity of demand in electricity prices. IEEE Trans Power Syst 2000;15(2):612–7. http://dx.doi.org/10.1109/59.867149.

[11] Venkatesan N, Solanki J, Solanki SK. Residential demand response model and impact on voltage profile and losses of an electric distribution network. Appl Energy 2012;96:84–91. http://dx.doi.org/10.1016/j.apenergy.2011.12.076.

[12] Zhao G, Zhan T, Xi H. Time-of-use price optimizing model and its solving method, no. Iccte. 2016, p. 892–6. http://dx.doi.org/10.2991/iccte-16.2016.154.

[13] Lv X, Li Q, Wang B, Zhang M, Wang D, Cao W. TOU optimization model of microgrid based on demand side response and economical operation. In: 2014 Int. conf. mechatronics, electron. ind. control eng. MEIC 2014, No. Meic. 2014, p. 71–6. http://dx.doi.org/10.2991/meic-14.2014.17.

[14] Rana AD, Darji JB, Pandya M. Backward/forward sweep load flow algorithm for radial distribution system. Int J Sci Res Dev 2014;2(1):398–400.

[15] Electricity Load profile of Nepal in 2073 | Nepal Electricity Authority - Datasets - Open Data Nepal. 2021, https://opendatanepal.com/dataset/electricity-load-profile-of-nepal-in-2073-nepal-electricity-authority. [Accessed 13 May 2021].

[16] Venkatesh B, Ranjan R, Gooi HB. Optimal reconfiguration of radial distribution systems to maximize loadability. IEEE Trans Power Syst 2004;19(1):260–6. http://dx.doi.org/10.1109/TPWRS.2003.818739.