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A game theory approach for OLTC voltage control operation in an active distribution network

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ABSTRACT

The integration of solar power generation using photovoltaic (PV) panels and increasing energy consumption has resulted in rapid voltage fluctuations in the distribution network. During peak demand and peak sun hours, the voltage fluctuation increases rapidly. These voltage deviations can cause undervoltage or overvoltage in the power grid, which are conventionally tackled using On-Load Tap-Changers (OLTCs). However, OLTCs have a slow response and causes frequent voltage instability, which affects the electrical power quality. Moreover, it can damage electrical equipment connected to the network and impose risk on service personnel. In conventional method, the tap changer of OLTC controls the voltage; however, in game theory method, an algorithm based on internal game theory is incorporated into the tap changer of OLTC to improve the voltage regulation. A 74-bus network is modelled in MATLAB to study the effectiveness of the two methods in regulating voltage during peak hours. In comparison to conventional method, game theory method decreased occurrence of voltage instability by an average of 69.4% and 61.6% during peak demand hour and peak sun hours respectively. Furthermore, it achieved a faster response by an average of 50% during peak demand hours and an average of 62.2% during peak sun hours.

1. Introduction

The electrical power system consists of three major sectors: Generation, Transmission network and Distribution network. The generation sector produces electrical energy, which is transmitted by the transmission network to the distribution network that provides power supply to consumers [1]. In recent years, Distributed Generations (DGs), typically driven by photovoltaic (PV) panels, are added to the distribution network, making it an Active Distribution Network (ADN) [2]. The PV panels are Distributed Energy Resources (DER), which are active resources capable of generating power at the consumer's side. Therefore, ADNs not only deliver power to consumers, but also generate and control the power flow in the network. This two-way power flow, due to the integration of DERs, introduces many challenges in maintaining the power quality levels in the ADN [3]. During peak hours, the demand for energy increases due to the usage of heavy loads. Besides this, the growth of economy and power industries has significantly increased power consumption and demand, which caused the power load to reach a new high [4,5]. Moreover, high penetration of PV panels in the power grid results in high solar power generation during peak-sun hour [6]. Due to the intermittent nature of the PV panels, there might be high power generation during periods of low demand. This can consequently result in voltage fluctuations in the ADN [7]. Therefore, the increasing power consumption and addition of renewable energy sources have resulted in a significant increase in the peak-valley load difference and inconsistency between power supply and demand [8,9]. These inconsistencies can result in over-voltage or under-voltage.

According to EN 50160, the supply voltage needs to be within ±10% on low voltage side. However, according to ANSI (American National Standard), the service voltage needs to be within ±5% of the nominal voltage level (1.0 p.u). In this paper, the ANSI standard is considered for voltage regulation. If voltage goes below 0.95 p.u, it results in undervoltage and if voltage exceeds 1.05 p.u, then it results in overvoltage in the network [10]. This can damage the equipment connected to the network and even impose danger to the service personnel of the electrical components. Therefore, it is crucial to maintain optimum electrical power quality, which can be done through regulating the nominal voltage [11,12]. Voltage regulation must meet three important requirements: satisfy user's demand, ensure safe operations of the system, and respect the equipment operating constraints [1].

A centralized voltage control scheme using control devices, such as

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Nomenclature

Abbreviations

ADN	active distributed network
DER	distributed rnergy resources
DG	distributed generator
FLC	fuzzy logic controller
GT	game theory
GTA	game theoretic algorithm
OLTC	on-load tap changer
PV	photovoltaic
RL	reinforcement learning
SVC	static VAR compensator
TSPF	time series power flow

Variables

B_{ik}, G_{ik}	constant
I	current
M	total number of players
N	total number of buses
P_i	active power at bus i
P_j	active power at bus j
Pd_i	active demand at bus i
Pg_i	active generation at bus i
Q_i	reactive power at bus i
Q_j	reactive power at bus j
Qd_i	reactive demand at bus i
Qg_i	reactive generation at bus i
S_i	apparent power at bus i
S_m	set of strategies available to player m
u_i	utility function
V	voltage
V_i	voltage at bus i
V_k	voltage at bus k
Y	admittance matrix
Y_{ik}	admittance between bus i and k
θ_{ij}	angle between voltage and current at bus i and j
δ_i	phase angle at bus i

On-Load Tap-Changers (OLTCs) and Static VAR Compensators (SVCs), can be used to regulate voltage within stipulated range in distribution network [9,13]. OLTCs are most widely used voltage control devices, which are installed on the primary side of the transformer in the distribution network to maintain a constant output voltage by changing transformer ratio. The OLTC adjusts the voltage in the bus bars due to changes in generation and load pattern, while ensuring no discontinuity in the power supply [13,14]. SVCs are also used to regulate voltage, but they are large and complex with high installation and maintenance costs. Moreover, its subsystems have moderate reliability and need improvement [15,16]. Thus, OLTCs are more suitable and feasible for voltage regulation in power systems. Despite the effectiveness of OLTC in controlling voltage levels, the device has several limitations. It needs frequent maintenance due to wear and tear and the tap changing mechanism of OLTC demonstrates a slow response which is undesirable during voltage regulation [14]. Moreover, due to increased fluctuation in voltage levels in the distribution network caused by sudden change in load and generation, the usage of the conventional OLTC alone is insufficient.

The peak demand hours as well as peak sun hours both occur for an average period of 5 h, with peak demand in the evening and peak sun hours being around the afternoon [17,18]. Conventional control methods using traditional OLTCs not only exhibit a slow response time in voltage regulation but also require frequent adjustments in tap positions during voltage fluctuations [19]. During peak hours, when the power consumption or generation continues to increase, the nominal voltage can be easily out of the statuary limit if conventional method is used. This is because OLTCs only respond whenever the nominal voltage is out of range and regulates only until the voltage is just within the desired range by changing the tap positions. Hence, upon further addition of load or generation, the voltage level can deviate from the range again, resulting in higher voltage imbalance during peak hours. This will further prolong the time taken for conventional method to regulate voltage during peak hours.

To overcome the limitations of OLTCs and enhance its performance, optimization algorithms can be incorporated to the tap changing mechanism of OLTCs [20]. Different optimization algorithms based on Game Theory (GT) as well as Q-learning, a form of Reinforcement Learning (RL), can regulate voltage in a network [21,22] . The algorithm based on Q-learning requires training using a dataset that consists of demand and PV generation voltage profile for at least 30 days. The process and technique used in Q-learning are difficult to implement algorithmically for a largescale application and can result in voltage problems if the training dataset is small [23,24]. On the other hand, Game Theory has been identified as a novel approach in solving problems in power systems, which can be used to design effective models based on real-world environments [21]. Therefore, game theory is chosen as the control method for its novelty and potential.

This paper proposes a novel approach where Internal Game Theory with stochastic dynamics is used to regulate voltage in the active distribution network via OLTC. Even though many different forms of GT have been used in power system for various applications, Internal GT has never been used before to solve problems in power systems. The main objective of this method is to develop and integrate Game Theory algorithm with OLTC so that occurrence of voltage instability can be reduced significantly during the peak hours as well as achieve an overall faster response compared to conventional method. The GT algorithm is designed to take into consideration the possibility of further addition of load or generation, so that voltage imbalance can be reduced during peak hours. We found that the GT algorithm reduces occurrence of voltage instability during peak hours by at least 50% and decrease the overall response time by at least 40% compared to conventional method.

The paper is organized as follows. The proposed method and methodology are discussed in Section 2. The case studies formed to analyze the effect of the proposed method is provided in Section 3. The results obtained, along with a comparison of the two methods, are presented in Section 4, and the conclusion of the work is provided in Section 5.

2. Proposed method

2.1. Power system architecture

In this paper, a 74-bus radial distribution network is used because it represents a real-world power system located in the Dagon Seikkan Township in Yangon, Myanmar. Moreover, load and branch data are available, which can be used to model the power system [25]. It has incoming lines of 33KV and outgoing lines of 11KV, which is also the distribution voltage. The system has a step-down transformer with a rating of 10MVA and 3 feeder lines. One of the feeder line hosts 56 bus bars while the other two has 4 and 13 respectively.

The 74-bus distribution network is an ADN, which enables the coordinated control of DGs, loads and network components such as OLTCs. This allows network components to take necessary switching actions to regulate voltage within its desired limits and minimize the fluctuations

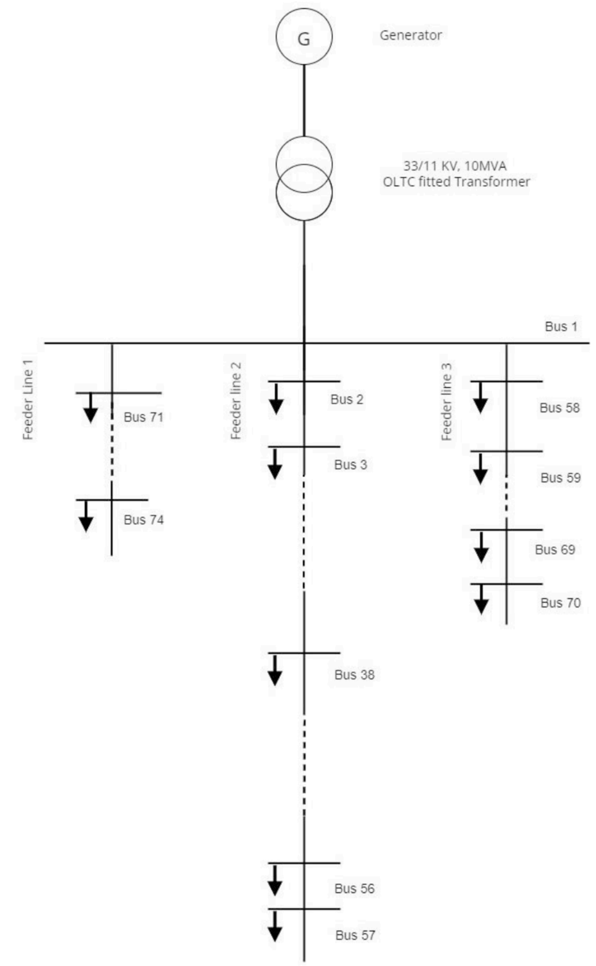


Fig. 1. Single Line diagram of the 74-bus distribution network.

caused by varying loads as well as high DG penetration [26]. In this network, bus 57 is connected to PV panels, which results in power generation at the consumers end during peak sun hours. Moreover, bus 57 has additional loads connected to it during peak demand hours, which increases the power consumption. The topology of the 74-bus distribution network is illustrated as a single line diagram in Fig. 1.

2.2. Load flow analysis

In order to regulate voltage, it is crucial to monitor important electrical quantities in the power network. This can be done by performing load flow analysis, which allows errors in the distribution network to be detected [27]. Moreover, it aids in designing power systems, addition of new transmission line as well as load centers. Power flow or load flow analysis is a mathematical approach to determine steady-state bus voltages, their phase angles, active and reactive power through each equipment in the network. The process of load flow analysis is outlined as follows:

The apparent power is computed for each bus as,

$$S_i = V_i I_i^* \tag{1}$$

The equation $I = YV$ is substituted in the above formula to yield the power flow equation shown below,

$$\frac{S_i^*}{V_i^*} = \sum_{k=1}^{N} Y_{ik} V_k \quad \in [1, N] \tag{2}$$

The power-flow equation can also be written as:

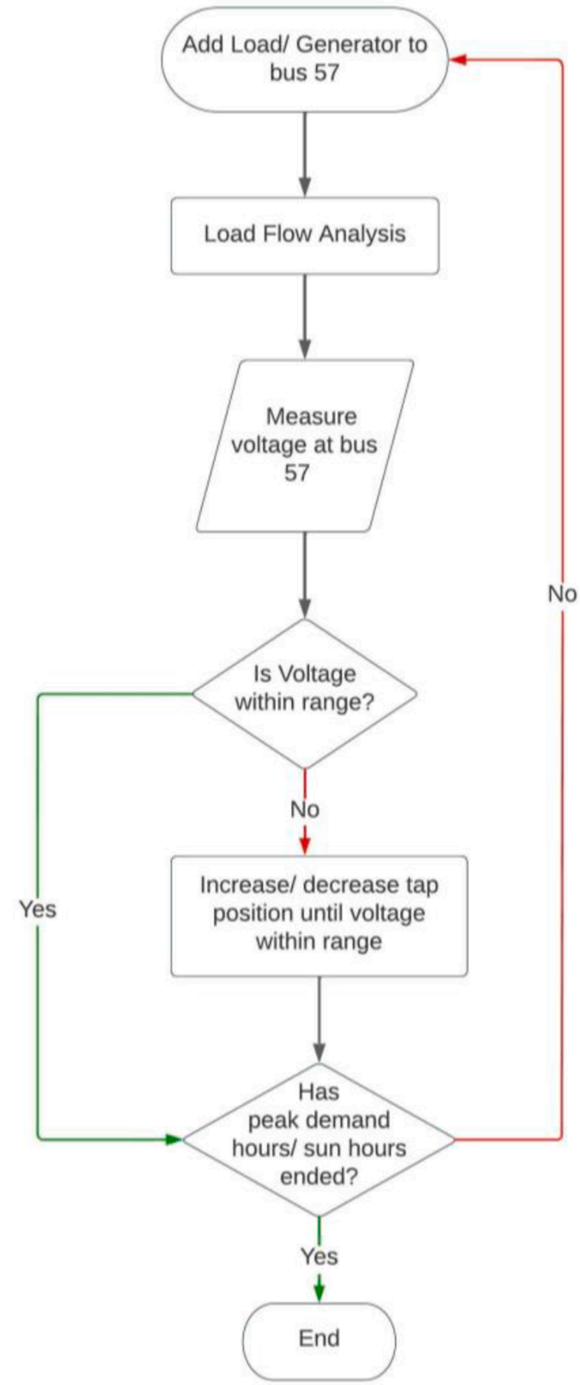


Fig. 2. Conventional Method Algorithm.

$$P_j = \sum_k |V_i||V_k| G_{ik} \cos(\Delta\theta_{ik}) + |V_i||V_k| B_{ik} \sin(\Delta\theta_{ik}) \tag{3}$$

$$Q_j = \sum_k |V_i||V_k| G_{ik} \sin(\Delta\theta_{ik}) - |V_i||V_k| B_{ik} \cos(\Delta\theta_{ik}) \tag{4}$$

The type of bus along with two of the four quantities, $|V_i|$, δ_i, P_i, and Q_i, at each bus are required to solve load flow problems. The active generations, Pg_i, and active demand, Pd_i, are used to find real power flows, whereas the reactive generations, Qg_i, and reactive demand, Qd_i, are used to find reactive power flows [28] . In this research, the load data and branch data of the 74-bus distribution network were used to perform power flow analysis on MATLAB to find the voltage profile of the network under normal condition. The distribution network is assumed to be a balanced three-phase system, where the loads are symmetrical. This means the loads are equally distributed in all the three phases of the system. Therefore, the voltage magnitude in each phase is equal in magnitude and differ in phase by 120°. The MATLAB files require bus data and line data of the distribution network so that load flow analysis can be performed using the Newton-Raphson method to produce the voltage profile of the network [29]. For load flow analysis, Newton-Raphson method is chosen because it exhibits fast convergence and requires a smaller number of iterations compared to other alternatives, such as the Gauss-Seidel method. Moreover, this method is simple and reliable [27,28].

The load and generation increase rapidly during peak demand hours and peak sun hours. Due to the time-varying parameters of the network, Time Series Power Flow (TSPF) is used to solve a series of power flow under different load and generation conditions. These series of power flow analysis are linked in time by ensuring that the parameters change from one series to another. Moreover, the initial values of power flow calculations of a series are taken from previous series. Therefore, Time Series simulations allows independent power flow analysis to be combined into a single timeline [30]. The effect of additional load or generation on the voltage level were observed by finding the voltage profile of the network after increasing active and reactive load or generator values in the MATLAB files. It was observed that under normal condition, bus 57 has the lowest voltage amongst all the bus bars in the system due to its position in the network. Because of this, bus 57 was chosen to study the impact of addition of load. For consistency, the same bus was chosen to study effect of addition of generation.

2.3. Conventional method

In the conventional method, traditional voltage control devices, such as OLTCs, are used to regulate the voltage in the distribution network with the help of communication infrastructure. Therefore, in the conventional method, the OLTCs are not incorporated with any optimization algorithm [24]. During under-voltage or over-voltage, the OLTC performs voltage regulation by changing the turns ratio of the transformer by adding or subtracting turns from the secondary winding. The OLTC adjusts the turns ratio in steps, normally 1.25% [31]. Therefore, in this paper, a single tap change of the OLTC is assumed to change the voltage by 0.0125 per unit. The OLTC is also assumed to have 17 tap positions available. The tap position ranges from -8 to +8, where tap position 0 corresponds to nominal voltage [20]. It allows the OLTC to maintain an output voltage that is within the desired range, which is between 0.95 p.u to 1.05 p.u [12]. The algorithm to test the conventional method is outlined in Fig. 2.

2.4. Game theory method

Game Theory (GT) is a mathematical model used to study the complex interaction among independent and rational-thinking stakeholders who can make decisions that benefit their own interest. A game theoretic model comprises three elements [32]:

- Players: The participants or stakeholders of the game. The players can be represented by M, where M= {1, 2, …, m}. In this paper, $M = 1$, as the OLTC is the only player.
- Actions: The set of strategies, S_m, available to the player m where m ∈ M. S denotes the set of strategy of all players. Therefore, S can be written as $S = \{S_1, S_2, \ldots, S_m\}$. The actions of the OLTC are the 17 tap positions available, which makes $S_1 = \{-8, -7, \ldots, 0, \ldots, 7, 8\}$.
- Payoff: This is a function used to quantify the benefit of each player, u_m,. It is also called the utility function, where u={u_1, u_2, .., u_m}.

The game is defined as an Internal Game with stochastic dynamics. The game is played whenever a voltage deviation is detected due to peak hours, where the peak hours are assumed to last for 5 h. Internal GT revolves around the idea that a player has inner conflicts, which causes a player to have multiple interests. It is crucial that the player has a rational set of actions. The rationality of the actions is determined by the completeness and transitivity of the actions available to the player. If a player is able to choose an action that is at least as good as the other actions, then the set of strategies is considered complete. The action set must also meet the criteria of transitivity. This means that if any player finds action 1 to be at least as good as action 2, and action 2 to be at least as good as action 3 then the player must find action 1 to be at least as good as action 3. A rational set of strategies can be used to formulate a utility function, where each strategy is ranked and assigned a real number to represent the ranking. The aim of the player is to choose an action that would maximize its utility function [33].

Table 1
Utility functions of tap positions.

Actions – Tap positions	Voltage within range after peak hours	Equal or less tap changes than conventional method	Utility function	Ranking
Start of peak demand hour				
1	0	1	u(1)	8
2	0	1	u(2)	7
3	1	1	u(3)	1
4	1	0	u(4)	2
5	1	0	u(5)	3
6	1	0	u(6)	4
7	1	0	u(7)	5
8	1	0	u(8)	6
Start of peak sun hour				
Actions- Tap positions	Voltage within range after peak hours	Equal or less tap changes than conventional method	Utility function	Ranking
-1	0	1	u(-1)	8
-2	0	1	u(-2)	7
-3	1	1	u(-3)	1
-4	1	0	u(-4)	2
-5	1	0	u(-5)	3
-6	1	0	u(-6)	4
-7	1	0	u(-7)	5
-8	1	0	u(-8)	6

The tap position of the OLTCs is ranked based on two criteria. One of the criteria is to check if any particular tap position successfully brings the voltage back to stipulated range while the other criteria checks if the total number of tap position required is less than or equal to that required by the conventional method. The best action is the one which meets both the criteria with the least number of tap changes and therefore is assigned the highest utility function. The remaining actions are ranked according to their ability in regulating voltage, with priority given to lower tap positions than higher ones. The action with the lowest ranking consists of those actions which fail to regulate voltage back to desired range. Therefore, the utility function depends on the aforementioned criteria and can be expressed as shown in Eq. (5):

$$u(i) = (V_i + E_i) \times \beta_i \quad (5)$$

where, i represents the tap position and β_i represents the belief associated with tap position, i . $V_i \in \{0,1\}$ represents whether tap position i can successfully regulate voltage after peak hour ends, and $E_i \in \{0,1\}$ represents whether tap position i is equal to or less than the tap position required in conventional method. Under stochastic dynamics framework, each action has a belief associated with it at a given time period, t, where the belief represents the chance of the action being chosen in that time period [33]. In this game, the time period, t, refers to the peak hours. The game commences when voltage deviation is first detected and an action is chosen, which causes the beliefs of all the actions to be updated for the next time period. For a player with multiple strategy or actions, the belief of the chosen action increases as shown in Eq. (6), where ε is a positive parameter

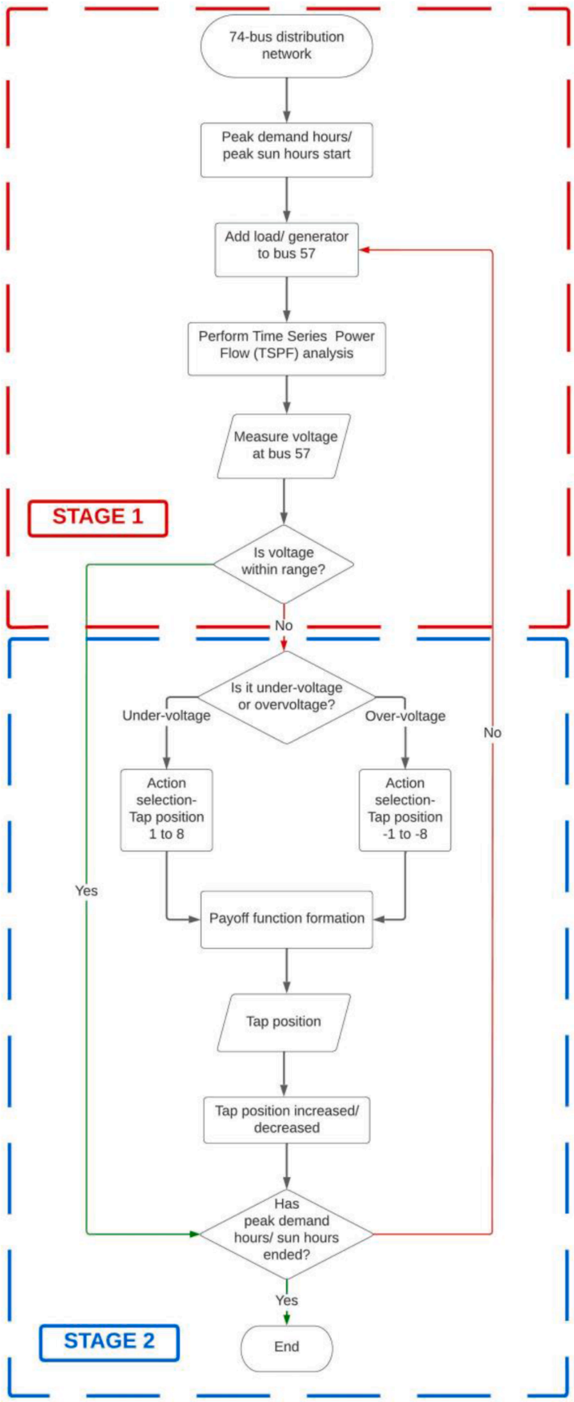


Fig. 3. Methodology to test Game Theory algorithm.

$$\beta_{i,t} = \beta_{i,t-1} + \varepsilon \tag{6}$$

For actions which are not chosen, the beliefs decrease as shown in Eq. (7), where A represents the number of available actions.

$$\beta_{i,t} = \beta_{i,t-1} - \varepsilon/(A-1) \tag{7}$$

The tap positions are ranked based on the value of the utility function. The higher the utility function, the higher the ranking. Therefore, tap positions with a ranking of 1 is considered the best action and is chosen by the OLTC to regulate voltage during peak hours. Table 1 shows the utility function of the tap positions at the start of the peak demand hour and peak sun hour, where the utility function is denoted as u(•).

Table 2
Case study.

Case Study 1: Peak demand hours (5 h)			
	Power factor 1	Power factor 0.95 leading	Power factor 0.95 lagging
Active Power added every hour (MW)	0.2	0.19	0.19
Reactive Power added every hour (MVar)	0	-0.06245	0.06245
Case Study 2: Peak sun hours (5 h)			
	Power factor 1	Power factor 0.95 leading	Power factor 0.95 lagging
Active Power added every hour (MW)	0.2	0.19	0.19
Reactive Power added every hour (MVar)	0	-0.06245	0.06245

2.5. Methodology

The proposed method is carried out in two stages. The first stage involves creating the 74-bus system model on MATLAB using the bus data and line data available and then testing the network under different circumstances, such as addition of load or generation, by performing TSPF analysis. To monitor the voltage level at each bus, load flow analysis is performed after every variation in load or generation at bus 57. The load flow analysis for each variation in load or generation is combined by performing time series simulation. If the voltage at bus 57 is within the statutory limit, no action is taken; however, if the voltage exceeds the limit, the second stage is carried out.

The second stage involves the regulation of voltage using game theory algorithm. The measured voltage at bus 57 is first identified as either under-voltage or over-voltage. This allows the set of strategies to be chosen from the available tap positions. In the event of under-voltage, the tap positions must be chosen from 1 to 8 to increase the voltage, whereas if overvoltage occurs the tap positions must be chosen from -1 to -8 to decrease the voltage at bus 57. Once the set of actions is selected, the payoff function is formulated for each action so that the OLTC can choose the action which results in maximum utility. Upon choosing the optimum action, the algorithm continues to monitor the voltage level to detect future deviations. Fig. 3 outlines the methodology used to test the GT method.

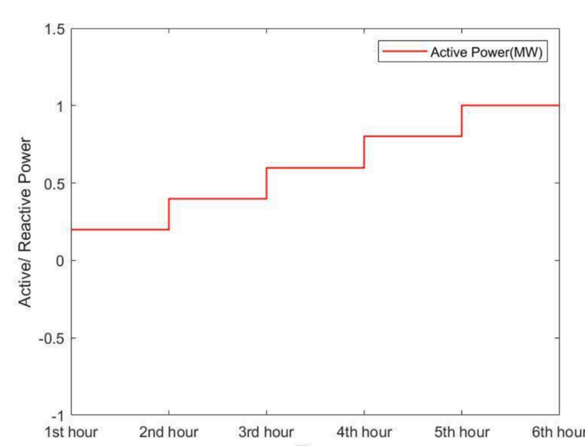


Fig. 4. Increase in Load/Generation when power factor is 1.

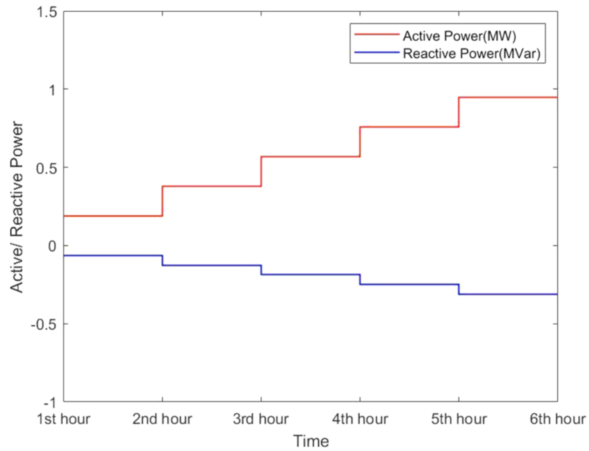


Fig. 5. Increase in Load/Generation when power factor is 0.95 leading.

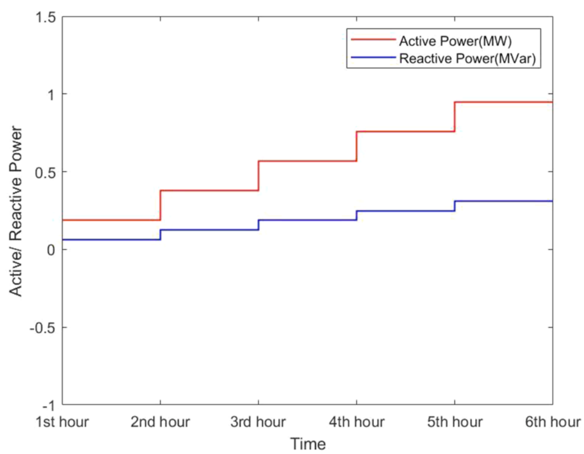


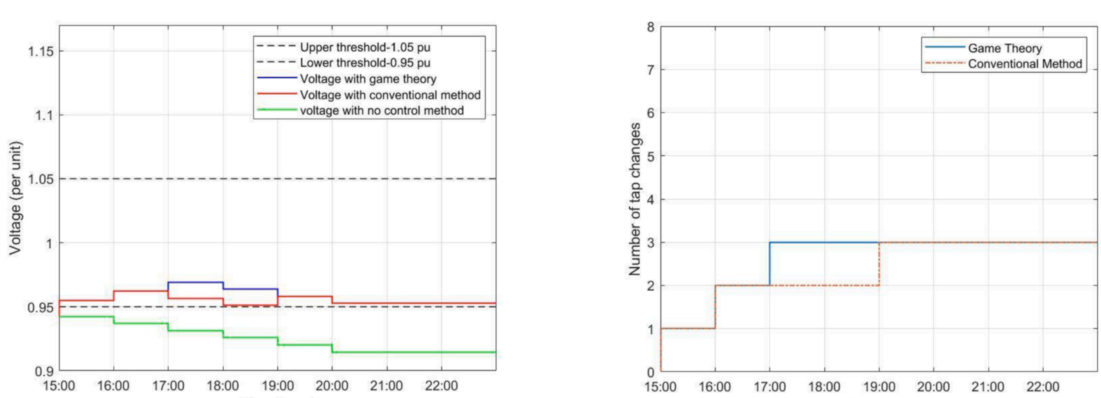
Fig. 6. Increase in Load/Generation when power factor is 0.95 lagging.

3. Case study

In this paper, two main cases- peak demand hours and peak sun hours- were considered. Each case had three subcases to study different variations of the main case. The two cases were based on the idea that the peak demand hours and peak sun hours cause a rapid increase in load and generation respectively. For the case study, both the peak hours are assumed to increase load or generation at a constant rate of 0.2 MVA/hour and last for 5 h, which is the typical duration [17,18]. For peak sun hour, it is assumed that bus 57 initially has a 5MW generator connected to it, so that further addition of generation will cause the voltage to be out of range and the effectiveness of the control methods can be tested. For the subcases, the power factor of the load and generators are varied to observe the effectiveness of the game theory algorithm under different power factors. The variations include unity power factor, 0.95 power factor leading as well as 0.95 power factor lagging. Table 2 shows the details of the cases. Figs. 4 to 6 shows how the load and generation is added to the network under different power factor.

4. Results & discussion

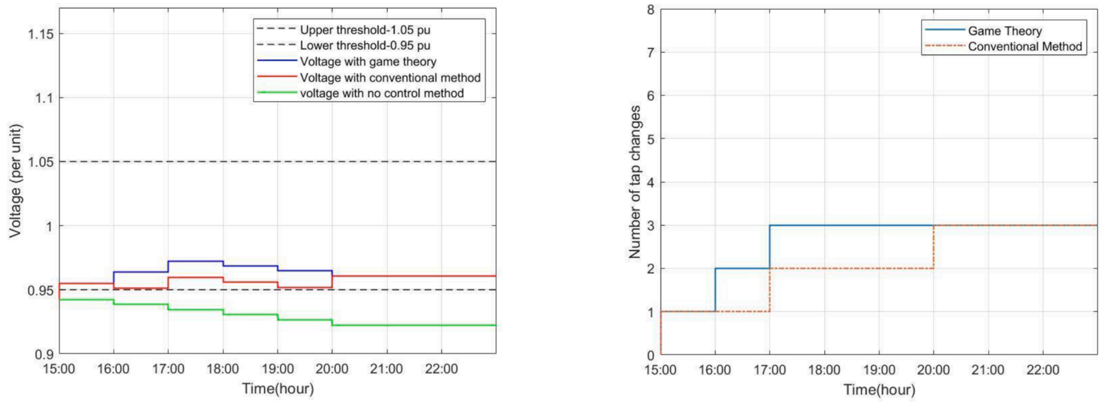
Figs. 7 to 9 show the voltage regulation at bus 57 as well as the tap change during the peak demand hours under conventional method, game theory method and when no control method is used. The voltage regulation and tap changes under different method during peak sun hours are shown in Fig. 10 to Fig. 12. The results obtained are summarized in Table 3, which shows a comparison between the conventional method and game theory method. The OLTC in both conventional and game theory method was assumed to respond immediately to voltage deviations. For voltage regulation with conventional method, each rise in voltage during peak demand hour and each fall in voltage level during peak sun hours means voltage level deviated from the range and was immediately regulated. However, the same cannot be implied for game theory algorithm as GT algorithm is designed to increase or decrease tap positions every hour until the chosen tap position with maximum utility is reached. This causes voltage levels to increase or decrease despite the voltage level being in the stipulated range. This is because GTA takes into consideration the possibility of future addition of load or generation to the network to prevent the voltage level deviate from the desired range during peak hours. The voltage regulation using conventional method appeared to have higher occurrence of voltage instability during the peak hours despite the power factor of the load and generator. Addition of load or generation would easily deviate the voltage from the safe range, resulting in voltage instability in the network. During both peak demand and peak sun hours, the network experiences voltage imbalance at least twice when conventional method is used. Moreover, conventional method causes the overall voltage regulation time to be longer by at least 2 h than when game theory method is used. The results obtained by using game theory showed significant improvement. The occurrence of voltage instability decreased by an average of 69.4% during peak demand hour while voltage instability happened 61.6% less during peak sun hours. For both peak hours, there were fewer voltage deviations under all power factors. Furthermore, game theory algorithm achieved faster voltage regulation.



(a) Voltage changes during peak demand hours when power factor is 1

(b) Tap changes during peak demand hours when power factor is 1

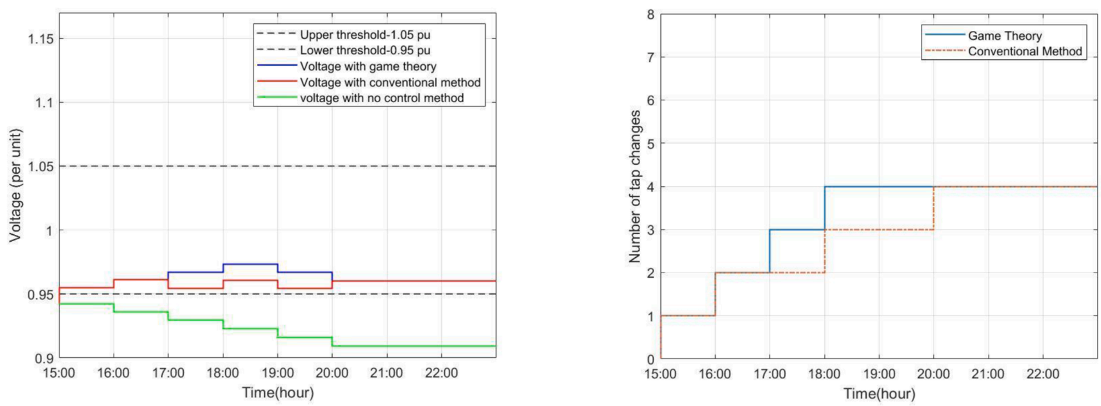
Fig. 7. (a) Voltage changes during peak demand hours when power factor is 1. (b) Tap changes during peak demand hours when power factor is 1.



(a) Voltage changes during peak demand hours when power factor is 0.95 leading

(b) Tap changes during peak demand hours when power factor is 0.95 leading

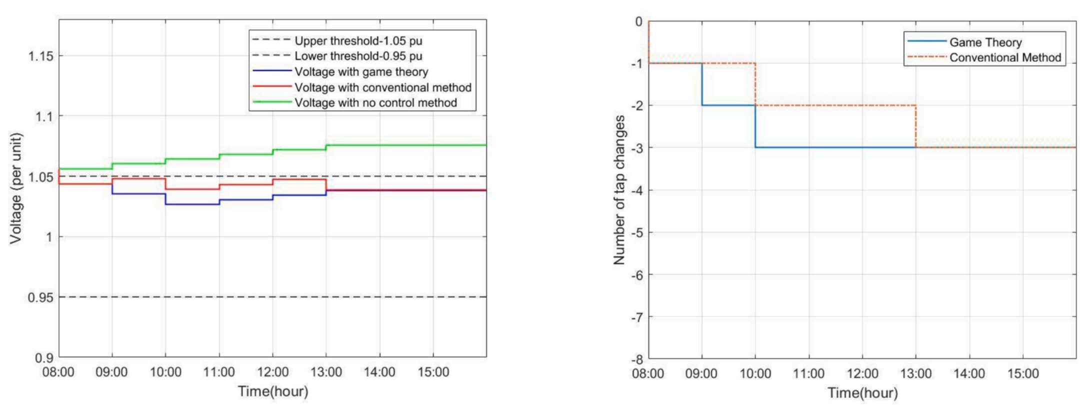
Fig. 8. (a) Voltage changes during peak demand hours when power factor is 0.95 leading. (b) Tap changes during peak demand hours when power factor is 0.95 leading.



(a) Voltage changes during peak demand hours when power factor is 0.95 lagging

(b) Tap changes during peak demand hours when power factor is 0.95 lagging

Fig. 9. (a) Voltage changes during peak demand hours when power factor is 0.95 lagging. (b) Tap changes during peak demand hours when power factor is 0.95 lagging.



(a) Voltage changes during peak sun hours when power factor is 1

(b) Tap changes during peak sun hours when power factor is 1

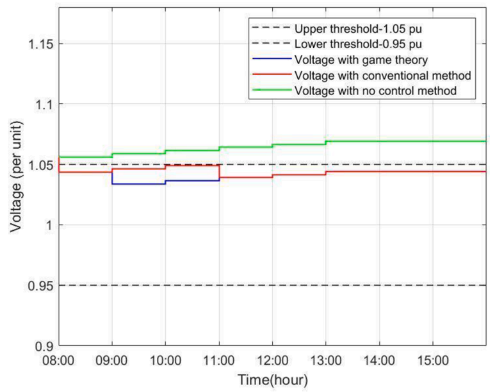
Fig. 10. (a) Voltage changes during peak sun hours when power factor is 1. (b) Tap changes during peak sun hours when power factor is 1.

The voltage regulation and tap changes under different method during peak sun hours are shown in Fig. 10 to Fig. 12.

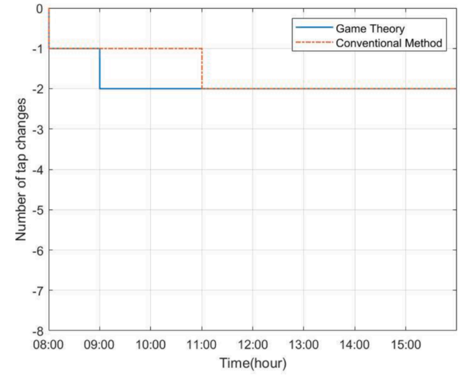
It exhibited a faster response by an average of 50% during peak demand hours while during peak sun hours, the response was faster by an average of 62.2%.

5. Conclusion

Conventional method, using traditional control operation of OLTC, demonstrates a slow response and requires frequent changes of tap position. This prevents a good electrical power quality to be maintained in

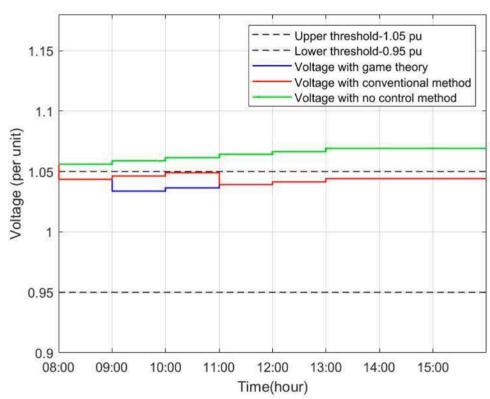


(a) Voltage changes during peak sun hours when power factor is 0.95 leading

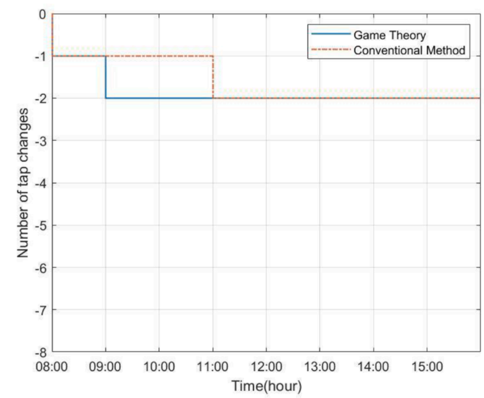


(b) Tap changes during peak sun hours when power factor is 0.95 leading

Fig. 11. (a) Voltage changes during peak sun hours when power factor is 0.95 leading. (b) Tap changes during peak sun hours when power factor is 0.95 leading.



(a) Voltage changes during peak sun hours when power factor is 0.95 lagging



(b) Tap changes during peak sun hours when power factor is 0.95 lagging

Fig. 12. (a) Voltage changes during peak sun hours when power factor is 0.95 lagging. (b) Tap changes during peak sun hours when power factor is 0.95 lagging.

Table 3
Comparison between conventional and game theory method.

		Peak demand hour			Peak sun hour		
Power factor		1	0.95 leading	0.95 lagging	1	0.95 leading`	0.95 lagging
Total voltage regulation time (hours)	Conventional method	5	3	5	5	3	5
	Game theory method	2	1	3	2	1	2
Game theory faster than conventional method by		50%	60%	40%	60%	66.6%	60%
Total occurrence of voltage instability	Conventional method	3	3	4	3	2	3
	Game theory method	1	1	1	1	1	1
Game theory causes less voltage instability by		66.6%	66.6%	75%	66.6%	50%	66.6%

the network. To resolve this, in this paper, a novel control method based on game theory algorithm was presented for voltage regulation in active distribution network during peak demand and peak sun hour. The game theory algorithm was based on internal game theory and was developed using MATLAB. The algorithm was tested on a 74-bus distribution network for mainly two cases- peak demand hours and peak sun hours. Each case had three subcases to test efficacy of the algorithm under different power factor of the load and generator. The results obtained were compared with that of conventional method to evaluate the effectiveness of game theory algorithm in reducing voltage instability and increasing overall response time. It was observed that GTA resulted in 69.4% less voltage instability during peak demand hours while it reduced voltage instability by 61.6% during peak sun hours. Moreover, the overall voltage regulation time decreased by 50% during peak demand hours and by 61.2% during peak sun hours. Therefore, it can be concluded that game theory algorithm successfully reduces occurrence of voltage fluctuations and regulates voltage faster than conventional method during peak demand hours as well as peak sun hours.

CRediT authorship contribution statement

Sarika Tasnim: Conceptualization, Investigation, Methodology, Formal analysis, Data curation, Writing – original draft, Visualization, Validation, Writing – review & editing. **Charles R. Sarimuthu:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Supervision. **Boon Leong Lan:** Writing – original draft, Visualization, Writing – review & editing. **Chee Pin Tan:** Writing – original draft, Visualization, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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