Proceedings of 13th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2023 Month: April Volume: 13

Central Control Charging Strategy of EV for Maximum Utilization of the Existing Electrical Network

Nikesh Manandhar [a], Ram Prasad Pandey [b]

[a] *Pashchimanchal Campus, IOE, Tribhuvan University, Nepal*
[b] *Department of Electrical Engineering, Pashchimanchal Campus, IOE, Tribhuvan University, Nepal*
[a] nikesh.manandhar@gmail.com, [b] ramprajwol@wrc.edu.np

Abstract
Nepal has seen a surge in the use of Electric Vehicles (EVs) in recent years, eradication of Load shedding, ever growing increase in the price of petroleum products, environmental benefits of EV driving their popularity. However, while the number of EVs on the roads has grown rapidly the charging infrastructure has not kept pace with this growth. In a primarily residential city like Kathmandu, EV charging stations are few and far between, and most EV owners charge their vehicles at home. This means that the power required to charge EVs is being delivered by the same transformer that supplies power to the residential area. This can cause problems because the inherent nature of residential load peaks in the evening, and the charging habits of EV owners may exacerbate this peak load and overload the distribution transformer and lead to power outages. To address these issues, a coordinated charging approach is proposed. This approach involves a central controller that receives information on the loading of all individual consumers, including EV owners. The controller then analyzes the network conditions and allocates an optimum charging profile to each EV connected, thereby making the maximum utilization of the existing network without overloading it. The EV penetration can be upto 250% more than in the case of uncoordinated charging. This strategy not only helps to shift peak loads away from the evening peak which can reduce the need for additional infrastructure investment but also charge the EV during the light load condition during the late night which help in Demand Side Management by smoothing the daily load curve.

Keywords
Electric Vehicles, Optimization, Bounded Simplex Method, DIgSILENT

1. Introduction

As per the data obtained from the Department of Transport Management(DoTM), Nepal is witnessing an annual growth of 16% in the total vehicles registered within its territory. With rapid urbanization, the annual growth rate is expected to rise in the future. Over 3.5 million vehicles are registered in Nepal by 2019. Among these over 90% are passenger vehicles, 96% of which are privately owned and only 4% are contributed by public vehicles. Although Nepal is aggressively adopting to EV vehicles, till date only 1% of the total vehicle fleet in Nepal is actually electric. Other 99% are petroleum based.[1]

To promote EV, diesel based three-wheeler were completely banned in Kathmandu Valley in the year 2000, which were replaced by Safa Tempos. Initially started with 7 tempos their number dramatically increased to 700 after the diesel based three-wheeler ban in 2000. According to DoTM data, there were 26,466 registered e-rickshaws in Nepal by 2019. Similarly, EV has also started to penetrate the private sector after the 2015 blockade imposed over Nepal, which saw a huge petroleum product shortage. As per data from EVAN(Electric Vehicle Association of Nepal) 6000 two wheeler and 1000 EV cars are currently operational in Nepal.

As per the annual report of Nepal Rastra Bank(NRB), petroleum products contribute to 13.68% of the total commodities imported in Nepal in the year 2019/2020. In the fiscal year 2019/2020 petroleum products worth Rs. 1,63,702 million rupees was imported, making it one of the major contributors to Nepal's trade deficit[2]. In contrast total revenue collected by NEA in the fiscal year 2020/2021 is Rs. 70,997 million rupees[3].

The lack of public charging station in Nepal is a major challenge for the promotion of EV. Currently, there are less than 20 charging station in the Kathmandu valley. Almost all of these stations are located at car showrooms of Hyundai, Kia, BYD, Sipradi or MG Motors; that makes it only accessible to those who own cars of these companies. None of them is in major areas of the city or a petrol station and none of them can charge two-wheeler [4]. NEA has recently awarded a tender to install 50 Public charging station all over Nepal. Norway which has the most EV friendly public charging infrastructure boast a total of 17,000 charging infrastructure within its border for supporting its EV fleet of 4,80,000. This implies Norway has atleast 1 charging station for every 28 EV on the road. In Nepal the public charging infrastructure isn't yet strong enough to support the current EV fleet. However, is it really necessary to invest in a separate charging infrastructure? We have already invested in a electrical grid infrastructure which is loaded for a short period of time each day. Using a cunning charging strategy which ensures the maximum utilization of the existing electrical network can save the capital required for building an entire dedicated charging infrastructure which may even become a burden in case of another scientific breakthrough in the field of locomotives.

The electrical grid is designed to meet the system peak and during the off peak time the grid is under utilized. If the load is mostly residential load then their is substantial reduction of consumption during the night. Hence, EV charging can be introduced as off-peak load in the electrical grid[5] .

K. Clement et al. [6] have highlighted the impact of EV charging on power losses and voltage deviation, and have emphasized the need for a coordinated charging approach to minimize these issues. As most EVs are parked and charged at home during the night, the authors propose an optimal charging profile that can minimize power losses and voltage deviation. This can be achieved through smart metering and direct coordination of the charging process, which involves sending signals to the individual vehicles. The proposed coordinated charging approach can help to ensure that EVs can be integrated into the residential grid at the optimum level while minimizing the impact on the grid.

Niroula et al. [7] have provided insights into the charging behavior of private EV owners in Kathmandu valley. The study involved the use of a questionnaire-based approach to collect responses from 150 respondents. The analysis of the data revealed that overnight charging at home location was the most preferred method of charging among EV owners. It was found that almost 80% of the EV owners charge their vehicles twice a week, with Monday and Friday being the preferred days for charging. The study concludes that the charging behavior of EV users in Kathmandu exhibits a dumb charging pattern. This implies that EV owners are not optimizing their charging behavior in a way that could benefit the grid and the overall energy system. The authors emphasize the importance of understanding the charging behavior of private EV owners for formulating future policies for smart charging and sustainable energy systems.

Bhandari et al.[8] analyzed the effects of Plug-in Electric Vehicles (PEVs) on the 11 kV distribution system in Nepal, with a focus on the Bageshwori feeder of Nepalgunj. The authors used a Monte-Carlo Simulation to determine the charging profile of the entire PEV fleet based on the daily driving distance and charge start time of individual vehicles. The study found that the load profile of the entire PEV fleet peaked at 8 pm in the evening, which corresponds with the system peak. As the penetration level of PEVs increases, the system peak, feeder power loss, and energy loss also increase while the load factor decreases. These issues can be addressed by changing the charging profile of PEVs to accommodate charging during off-peak hours of the system.

Richardson et al. [9] have created an ideal charging strategy where the charging rates of a test network with a high penetration of EVs may be tuned to give the most energy to the EVs within a predetermined charging time while guaranteeing that the underlying residential load is not impacted. They have demonstrated that an ideal charging technique would offer important advantages for supporting high EV penetration.

2. Methodology

2.1 Low Voltage Network

A LV Network of a 125 KVA transformer located at Bagbazzar, Ratnapark is taken as a reference network. The network data is collected from Ratnapark Distribution System. Around 92 single phase Residential/Commercial load and 2 three phase commercial load is connected to this distribution transformer. The length of the LV network is around 1.35 km mostly made up of 4-wire Weasel conductor supported by 28 electric poles. Around 21 randomly selected residential/commercial/industrial consumer's data from Ratnapark DCS is obtained from the Kathmandu Valley Smart Metering Project. The data obtained is hourly loading data for a single day. Consumers connected to the 125 KVA network are randomly assigned the load profile from the collected load profiles. With these data, a sample LV network is modeled in DIgSILENT Powerfactory. A quasi dynamic simulation is then performed which will give us 135 individual load flow results at an interval of 15 minutes.

2.2 Data Collection for EV

In order to study the current impact of EV on the electrical grid the current scenario of the presence of the EV has to be analyzed first. The charging requirement of the EV largely depend on their own daily use, the range of the EV and the battery capacity. The range and battery capacity of the EV is determined by the model of the EV being used whereas the daily use is based on the individual's requirement and differ from user to user. Another factor to be taken into consideration is the individual's charging habit. Although, the public charging station infrastructure is slowly developing inside Kathmandu Valley most of the current EV users charge their vehicle from the wall socket of their own home.

For collecting these relevant data like Vehicle Model, Daily Destination, NEA Consumer number an online tool using Javascript and Google Web Hosting platform is created. This tool is circulated through online social media platforms where users can provide their data for research purpose. Once these data are collected the EV charging profile of the EV users currently located within Maharajgunj DCS and Ratnapark DCS can be easily obtained through the Smart Meter already installed by NEA.

2.3 Electric Vehicle

Currently, a number of EV choices are available in the Nepalese market. However, for the purpose of this study, EV having a battery capacity of 64 kWh, charger capacity of 7 kW and charging time of 9 hours is considered. The Electric Vehicle's impact on the electrical grid is limited to the charging period. During this time, the EV can be modeled as a static load equal to the charger capacity. The static load is connected to the grid only for the duration of the charge and disconnected once the battery reaches full capacity.

2.4 Central Control Charging strategy

In the Central Control Charging (CCC) strategy, the DSO invests in a communication network. This enables a central controller at each distribution transformer to monitor the power usage and voltage conditions of each consumer connected to the transformer. The central controller uses this information to create an optimal charging profile for each connected Electric Vehicle. The profiles are then sent to the chargers via the communication network, to be followed until the next evaluation period.

The objective of CCC strategy is to maximize the amount of power delivered by the individual charger subjected to certain constraints. The objective function of CCC strategy is defined by Equation 1[10]

$$Maximize\ \ CCC = \sum_{i=1}^{N} EV_i cc_i \tag{1}$$

EV_i is the Power delivered by the EV charger connected at i^{th} bus. cc_i is charger condition at i^{th} bus, denoted by either 0 or 1.

The above optimization problem has the following constraints:-

$$0 \leq EV_i \leq EV_{max} \tag{2}$$

EV_{max} is the maximum rated output power of the EV charger. The power delivered by the EV charger can vary in a continuous manner defined by Equation 2

$$EV_i^{t-1} - \triangle \leq EV_i^t \leq EV_i^{t-1} + \triangle \tag{3}$$

t is the current time step and $\triangle$ is predefined limit in kW by which the charging rate can vary. Equation3 helps to avoid large variation in charger output.

$$V_{min} \leq V_i \leq V_{max} \tag{4}$$

At the end of every time interval, the central controller checks the voltage at every bus. The voltage at every bus has to be maintained within the range of Equation 4

$$L_{TR} \leq L_{TR_{max}} \tag{5}$$

Similarly, at the end of every time interval, the central controller checks the loading of the transformer which needs to be kept below the maximum rating of the transformer as given by Equation 5

2.5 Network Sensitivities

An addition of EV at the CPOC causes the voltage drop at every bus bar. This idea is used to relate the voltage constraints as given by Equation 4 to the power requirement of each EV. The parameter which relates this is called the voltage sensitivities. For the CCC strategy, the network voltage sensitivities due to the addition of the EV has to be predetermined.

In order to determine the voltage sensitivities a time-series, unbalanced, three-phase load flow analysis of the distribution network is performed in order to determine the network voltage levels at each bus as a result of the non EV consumer load. Then, at each bus the EV load is perturbed by a small amount as given by Equation 3. For each perturbation the load flow analysis is repeated to determine the changes in the network voltage levels. The change in voltage due to the small change in EV load in recorded and the voltage sensitivity is calculated.

$$\mu_{ij} = \frac{\Delta V_i}{\Delta EV_j} \tag{6}$$

μ_{ij} is the voltage sensitivity of bus i due to the change in power at bus j. Hence, for a distribution network having n-bus, a nxn matrix is created. Analysis of the load flow results shows that the assumption of linearity for the voltage sensitivity characteristics is adequate [11]. Using the Voltage Sensitivity the constraint for the voltage level as given by Equation 4 can be rewritten as

$$V_{min} \leq V_i^{t-1} + \mu_{ii}\Delta EV_i + \sum_{j=1, j\neq i}^{N} \mu_{ij}\Delta EV_j \leq V_{max} \tag{7}$$

V_i^{t-1} is Voltage at the CPOC during previous load flow. μ_{ii} is Voltage sensitivity of i^{th} bus due to change in load at i^{th} bus. μ_{ij} Voltage sensitivity of i^{th} bus due to change in load at j^{th} bus.

2.6 Optimization Method

The objective function given by Equation 1, subject to the constraints given by Equation 2,3,5 and 7 is a linear variable optimization problem where the decision variable have a fixed lower and upper bound. Such optimization problem can be solved using the Revised Simplex Bounded Variable Algorithm.

3. Results and Discussion

3.1 Voltage Sensitivity

The current distribution system has 28 number of poles. Thus, the resulting Voltage Sensitivity matrix would be a $28x28$ matrix. The Voltage Sensitivity matrix for the given distribution network is shown below.

$$\begin{bmatrix} -0.0066 & -0.0281 & -0.0008 & ... & -0.0002 \\ -0.0067 & -0.0930 & -0.0048 & .... & -0.0045 \\ -0.0067 & -0.0930 & -0.0048 & .... & -0.0046 \\ .... & ..... & ..... & ..... & ..... \\ -0.0067 & -0.0930 & -0.0048 & ..... & -0.0045 \end{bmatrix}_{28\times 28}$$

Figure 1: Voltage Sensitivity Index

In order to confirm the validness of these Voltage Sensitivity, we randomly select a bus for voltage measurement. Load are randomly added or subtracted from randomly selected buses. With the new network loading condition, we can perform load flow analysis for determining the new voltage levels. These voltage determined from the load flow are compared with the voltage as determined by Equation 8

$$V_{new} = V_{init} + \mu_{ii} * \Delta P_{ii} + \sum_{j=1, j\neq i}^{N} \mu_{ij}\Delta Pij \tag{8}$$

3.2 Uncoordinated Charging

The case of uncoordinated charging is analyzed by adding EV on Pole 8, 9 ,10, 27 and 24. All the EV were added simultaneously at 5 pm which denotes the time when the vehicle return to home. Just adding 5 EV on the distribution network the transformer

Table 1: Voltage Calculation Using Voltage Sensitivity Index

Bus	Power Change on Bus	ΔP	Voltage obtained from Load flow	Calculated Voltage using VSI	%Error
1	1,2,6,10	0.4,1.2,1.1,2.1	0.238747	0.238747388668	-0.0002%
7	3,4,8	2.77,3,5	0.234775	0.234688262	0.0369%
8	2,1,20	2.5,-0.25,2.2	0.233807	0.233806731	0.0001%
10	1,2,3,4,5	2,3,-0.5,5,2.4	0.231935	0.232243128	-0.1329%
19	11,17,19,21	1.5,1.89,2.33,4.44	0.229482	0.229482367	-0.0002%

was found to be overloaded upto 150 percent at 8 pm in the evening(Figure 3). This clearly coincide with the peak load during the evening peak. However, the system is lightly loaded during the late evenings and early morning hours as seen in Figure 2. Charging strategy targeting these hours can improve the overall system performance.

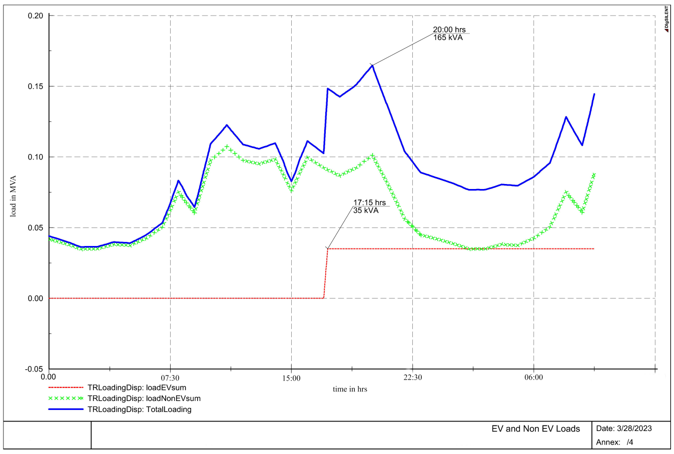

Figure 2: Apparent Power of EV, NonEV and Total load during Uncoordinated Charging

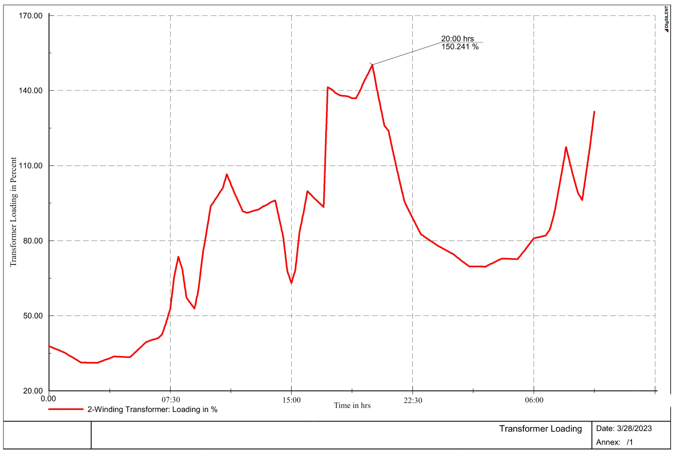

Figure 3: Transformer Loading in percent for Uncoordinated Charging

3.3 CCC Control Strategy

When the CCC Control Strategy is applied, instead of charging the vehicle at a constant power, the power of the charger is controlled by a controller which is depended on the voltage at the CPOC and the loading of the transformer. At each sampling time interval, the current voltage and loading data is provided to the Central Controller which analyzes the data and generates a optimum charging power for each connected EV(Figure 5. Using such strategy, the number of EV connected on the distribution system can be increased upto 11 without overloading the transformer(Figure 6

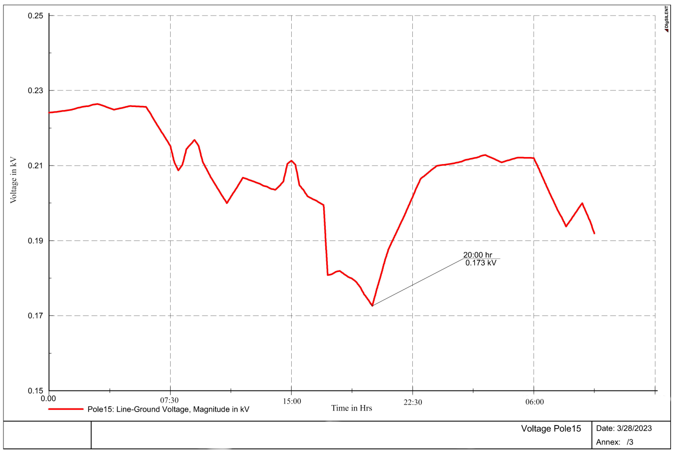

Figure 4: Voltage Profile at the furthest pole during Uncoordinated Charging

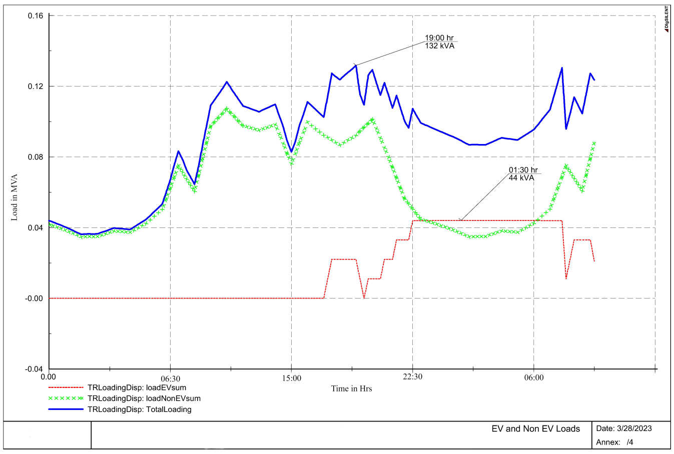

Figure 5: Apparent Power of EV, NonEV and Total load during Coordinated Charging

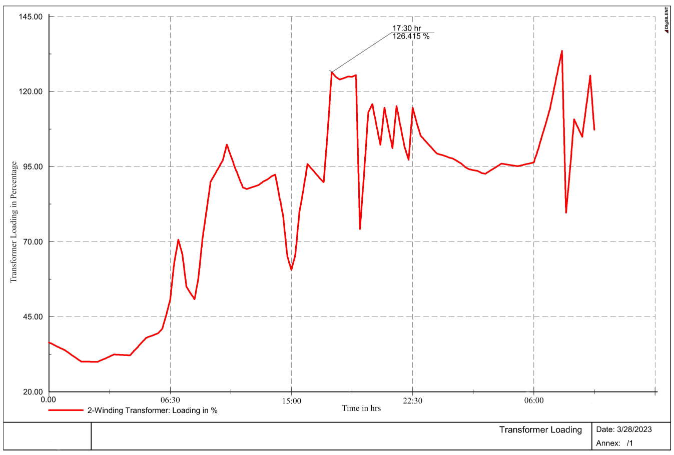

Figure 6: Transformer Loading in percent for Coordinated Charging

4. Conclusion and Recommendation

With rapid increase in EV, the strain caused by it on the distribution network is a major concern for the DSO. With

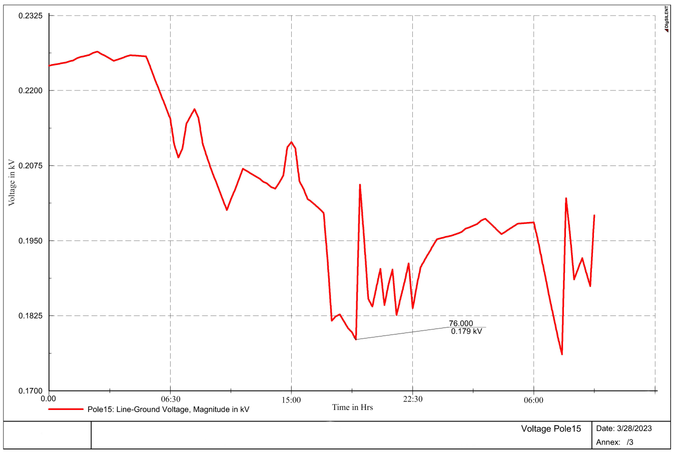

Figure 7: Voltage Profile at the furthest pole during Coordinated Charging

uncontrolled charging of EV the system suffers from premature overloading even at a low penetration of EV, which is a major concern for the DSO as they will have to upgrade their network to address such overloading. However, if a coordinated charging strategy is employed not only the network can withstand a penetration of more than 250% of the penetration during uncontrolled charging but shifting the EV load during the night ensures improved load factor which is a great opportunity for the DSO to sell more electricity using the existing electrical network. Since AMI is already employed by NEA, they should try to incorporate data obtained from AMI toward the developments of coordinated charging strategy. Currently, charging strategy developed in this paper is based on the assumption that the EV load are static load. Thus, we can develop a smart electric vehicle charger which employs such coordinated charging strategy as future research work.

Acknowledgments

The authors acknowledge Er. Manoj Aryal of Ratnapark DCS for providing the necessary line data and consumers data from the AMI platform installed at Ratnapark DCS, which served as a basis for the analysis.

References

[1] Dr. Radha Wagle. *Assessment of Electric Mobility Targets for Nepal's 2020 Nationally Determined Contributions (NDC)*. 2021.

[2] Government of Nepal. *Annual Report Nepal Rastra Bank*. 2021.

[3] NEA. *Annual Report Nepal Electricity Authority*. 2021.

[4] Shashwat Pant. Kathmandu needs more charging stations for evs including two-wheelers. but, the transition doesn't look easy. *onlinekhabar*, 2021.

[5] K Schneider, C Gerkensmeyer, M Kintner-Meyer, and Robert Fletcher. Impact assessment of plug-in hybrid vehicles on pacific northwest distribution systems. In *2008 IEEE power and energy society general meeting-conversion and delivery of electrical energy in the 21st century*, pages 1–6. IEEE, 2008.

[6] Kristien Clement-Nyns, Edwin Haesen, and Johan Driesen. The impact of charging plug-in hybrid electric vehicles on a residential distribution grid. *IEEE Transactions on power systems*, 25(1):371–380, 2009.

[7] Prashant Niroula, Nepal Kathmandu, Ravikant Chaudhary, Riti Newa, and Binay Paudyal. A study on charging behavior of private electric vehicle owners in nepal. 2020.

[8] NPSMG Ganesh Bhandari, Nirmal Paudel, Sanjeev Maharjan, and Samundra Gurung. Impact assessment of plug-in-electric vehicles on distribution system through home charging. In *10th IOE Graduate Conference*, 2021.

[9] Peter Richardson, Damian Flynn, and Andrew Keane. Optimal charging of electric vehicles in low-voltage distribution systems. *IEEE Transactions on Power Systems*, 27(1):268–279, 2011.

[10] Peter Richardson, Damian Flynn, and Andrew Keane. Local versus centralized charging strategies for electric vehicles in low voltage distribution systems. *IEEE Transactions on Smart Grid*, 3(2):1020–1028, 2012.