European Journal of Research Development and Sustainability (EJRDS)
Available Online at: https://www.scholarzest.com
Vol. 2 No. 5, May 2020
ISSN: 2660-5570

A REVIEW ON CONCEPT OF ELECTRIC SPRINGS WITH ELECTRIC VEHICLE ON POWER NETWORKS

NIPIN K K
Assistant Professor, Department of Electrical Engineering, Dr. D Y Patil Institute of Technology, Pimpri, Pune, Maharashtra, India
imnibi13@gmail.com
Rajashree R Bhokare
Assistant Professor, Department of Electrical Engineering, Dr. D Y Patil Institute of Technology, Pimpri, Pune, Maharashtra, India
Rajashree.bhokare2020@gmail.com
Pankaj Kumar
Assistant Professor, Department of Electrical Engineering, Dr. D Y Patil Institute of Technology, Pimpri, Pune, Maharashtra, India
pankajku3012@gmail.com

Article history:
Received: April 11th 2021
Accepted: April 22th 2021
Published: May 22th 2021

Abstract:
The global concern of climate change lead the world to shift from fossil fuel driven economy to sustainable and green economy. Even the automobile sector is also driving fast towards Electric Vehicles (EVs). The penetration of EVs enhances sustainable and green development but introduce heavy burden on power sector. The challenges emerged due to penetration of EVs need to be addressed and answered through suitable solution. In this paper the most vulnerable issue due to ed. Electric Spring (ES) concept is combined in EV system to furnishEVs integration in power network is addressed and suitable solution is provid the issues like voltage and power instability, energy storage requirements etc. The Electric Vehicle-Electric Spring (EV-ES) technology is presented at charging stations and roof mounted solar powered hybrid electric vehicles.

Keywords: sustainable and green economy, Electric Vehicles (EVs), Electric Spring (ES), power network

1.INTRODUCTION

From past few years, world is moving towards a clean, better and quality power through renewable energy sources (RE). Even many countries are trying hard to resolve the problem and issues related to global warming. India is also keen focused to contribute towards clean environment in power sector by minimizing the use of conventional source of energy. Since, the Indian automotive industry has not concentrated much on its fossil fuel consumption but already took initiative to promote electric vehicles (EV). In complete sense, solar powered vehicle is still to be launched but some solutions were put forward to charge traction batteries in hybrid solar vehicles [1]. For instance, many vehicle manufacturers in India have started to think to incorporate solar system for powering fans, lights and auxiliary circuitry. But before introducing EV into Indian automotive market, certain issues related to power grid has to be addressed with appropriate solutions. EV connected to the grid with other connected loads (critical and non critical) will increase the volatility of the grid which is serious concern. As a result, the whole system undergoes the problem of voltage instability and issues related to load demand management due to the overload caused on transmission lines. Since the penetration of RE sources in power sector is gaining momentum with high speed, it will be quite difficult to determine the instantaneous total power generation in real time. Hence balance of power supply and load demand is a highly concerned matter that to be achieved. By taking account of this, upcoming control should be "load demand following power generation" for power system stability as discussed in [2], [3]. The influence of EV charging on voltage stability has been studied in [4] with an assumption of EV charging load as constant power load. It is important to study and analyze the static and dynamic voltage stability with RE connected to the grid and extreme load fluctuation while considering power quality issues. Due to EV integration, an approach has been taken by distribution system operators (DSOs) to bring changes in the low-voltage grid operation incorporating greater system complexity [5], [6]. Due to lack of voltage regulation on load connections, distribution system faces high voltage unbalances, raises concern about the grid reliability at low voltage distribution network because of substantial increase in peak load [7, 8]. Also, uncontrolled EV charging in such system causes high power quality deteriorations [9]. The shifting towards load demand following power generation brought up a novel concept of electric spring [10], a new smart grid technology which features for regulating the mains voltage of power grid with substantial intermittent renewable power. So when the scenario comes of incorporating renewable powered electric vehicle with power grid voltage stability and well planned load management, combination of EV-ES will be one of the future ideas in automotive area. From recent years research and efforts have been made to realize high dc-dc conversion with certain topologies like voltage multiplier [9], switched capacitor/inductor [11-13], voltage-lift [14], coupled-inductor [15], and cascade techniques [16]. Later again advancements were made with Z-source network [17] and then subsequently modifications were made to boost the dc voltage enhancing the efficiency and cost. EV-ES combination can play a vital role stabilizing the power quality issues due to Plug-in Electric Vehicles (PEV). One of the features of PEV is that it can serve as distributed energy storage unit. PEVs use on board chargers which in turn benefits utility grid [18-19]. On board charger have the unidirectional power flow capability which converts the ac grid voltage into dc. In addition to this on board chargers provides power quality functions as compare to other conventional methods. This includes reactive power compensation (inductive as well as capacitive), voltage regulation, harmonic filtering, power factor correction [20-24] for mitigation of power quality issues. Presently, Capacitor banks, Static VAR compensators, UPFC technologies, static synchronous compensators [25-30] are encouraged for reactive power consumption in residential loads. Unlike all other traditional compensators discussed above, electric spring will feature reactive power compensation as well as automatic load variations. Even compare to on board chargers, the additional features of EV-ES system comprises of active and reactive power compensations, automatic load variations and reduce energy storage devices in power grid [31, 32]. Battery state of charge also will not be affected by reactive power support as utility grid supports the ac-dc conversion losses due to reactive power compensation. EVs driven by excess solar or wind energy could decrease demand diversity. The ultimate purpose of the charging station for EVs is to provide continuous supply irrespective of the generation uncertainty. This means that EVs should be treated as a critical load. This could be very difficult if the power generation is through renewable energy sources. Hence the EV-ES system provides much better solution in charging stations for grid stability with RE and EV integration. So EV-ES combination can be implemented in EV charging station and also have an impact on roof mounted solar cells electric vehicle.

2. ELECTRIC SPRINGS

2.1 Principle of Electric Spring:

Electric Spring, a smart grid technology had shown its impact in power system by stabilizing smart grid. It has proven to be an emerging technology which enables load demand to follow power generation. As we know that power sector is growing rapidly with intermittent renewable energy (RE) sources. The more and more penetration of renewable energy in the grid raises many issues like voltage instability, voltage unbalance, power quality issues, over loading etc. Hence power grid demands advanced control methodologies and well planned strategies. The mixture of power electronics and advanced communication technologies provides an alternate solution for load management with RE sources. By considering all the factors, a novel technology has been introduced called electric spring. Electric spring is simply a power inverter associated with loads (non critical) to form a smart load. The simplified control diagram of electric spring configuration is shown in the fig 2. Electric spring can instantaneously manage and balance the power consumption and generation

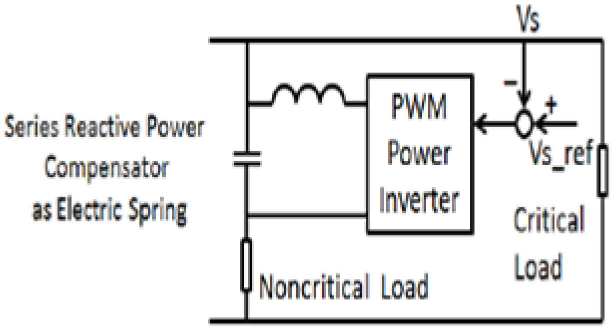

Fig. 1 simplified control diagram of electric spring configuration

2.2 Features of Electric Spring: Any electrical appliances embedded with electric spring can be turned into smart load. There are various methods available for load management but among all, electric spring is a promising power electronic technology which follows the control paradigm of load demand follow power generation. The technology has an advantage over other existing demand side management [32-37] techniques and energy storage solutions [38, 39]. It can reduce the voltage fluctuation caused by unstable power generation in real time. Electric spring can reduce the requirement of energy storage in the system by 50% which is clearly explained in [31]. Electric spring technology is highly preferred for load compensation, distributed power compensation and dynamic voltage stability. It can provide both active and reactive power compensation and combination of both. It also improves power quality issues of the distribution power grids. So this technology is treated as decentralized approach as compared to single centralized techniques.

2.3 Modes of operation: Basically Electric spring works on three modes: Normal mode (neutral position), Voltage boosting mode (voltage support mode) and voltage reduction mode (voltage suppressing mode).

The relationship of the ES voltage Ves, line voltage Vs, and non-critical load voltage Vo is given by

$$V_o = V_s - V_{es} \qquad ……….(1)$$

The fundamental equation of ES to regulate the line voltage When supply voltage is in its nominal value, ES gets isolated and Vo equals to Vs,. As shown in the figure (a). When Vs goes beyond the nominal value, the ES comes into action instantaneously to generate a voltage Ves to suppress Vs to its nominal value, as shown in Fig. 3(b). On the other hand, when Vs drops below its nominal value, the ES instantaneously generates a voltage Ves to boost Vs to its nominal value, as shown in Fig. 3(c).

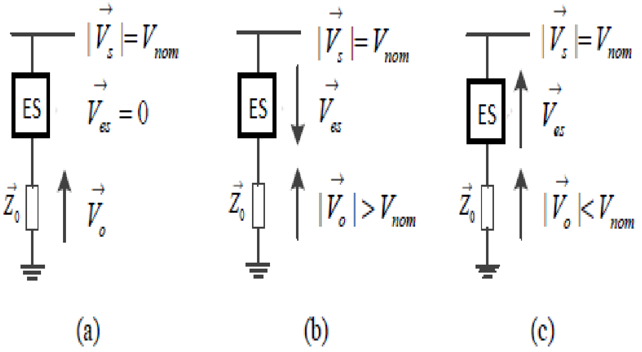

Fig. 2 Modes of operation of electric spring

3. EFFECT OF EV INTEGRATION ON POWER NETWORKS:

Introduction of EVs in the market brought opportunities as well as challenges too whether in terms of infrastructure, service or policies. The usage EVs also affect the power sector either at demand side or at installation point. The rapid installation of multiple charging stations or infrastructure impacted the energy strategy. Integration of EVs into the grid may lead to severe problems on the power grid and as well as on the distribution networks. The subsequent increase in the load simultaneously along with EVs cause the major issue to power network. The impact of electric vehicles in power distribution networks is clearly analyzed and presented in [40]. The paper concluded that the deployment of EVs creates issues in supply demand matching and affects voltage profiles. The requirement of voltage stability and energy storage can be achieved by the incorporation of electric spring concept with EV system.

4. CONCEPT OF ELECTRIC SPRING IMPLEMENTATION IN ELECTRIC VEHICLE SYSTEM

4.1 In charging stations: The rise of electric vehicles will show adverse effects on distribution systems. It may also lead to significant demand increase on low voltage (LV) distribution systems. Uncontrolled charging could lead to problems like grid instability, thermal overload of transformers and lines, voltage deviation and instability, harmonics, problems in reactive power compensation and phase unbalance. [41] Proposed centralized and distributed electric vehicle charging algorithms, and compared their performance in simulations with real vehicle data, on a model based real LV network.

In the past a wide research has conducted regarding the charging of electric vehicles and establishing the charging station for the same considering different factors related to grid stability, issues related to power system, RE integration and battery management. The detail of solar powered charging station for electric vehicles is presented in paper [42]. A number of solar panels can be placed on the roof of the charging station for charging the electric vehicles coming to the charging station. The working of charging station is clearly mentioned in [43].

Every charging station or we can say Electric Vehicle supply Equipment (EVSE) system consists of physical components, software applications and on-going service. The physical components involve internal electronics, controllers, cord, EV-compatible plug and telecommunications devices to share data and enable network connections. The need of software applications is to manage the charging, billing, driver access, and administration of an EVSE program. On-going service maintains physical and software components. It also provides customer service to both EVSE owners and their driver constituents. The power electronics assembly is the main part of a charge station. It supplies the power to the EV's onboard battery charger. The on-site receptacle/electric panel is the demarcation point between the power grid and the beginning of the EV charging station system. The charging station configuration with ES system incorporated is shown in the Fig. 3. The System shows both AC charging and DC charging. Every vehicle has an on board charger which can be charged through AC mains supply either from home or from charging station. The problem with AC charging is that it provides limited power and slow charging. Both these reasons lead engineers to move towards DC or fast charging method. In DC charging, the grid provides required power to the DC fast charging station through which the vehicles can be charged at the charging station. DC charging technique is capable of integrating the renewable energy sources.

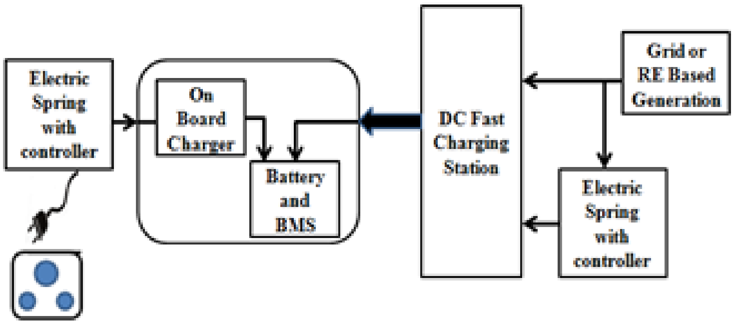

Fig. 3. Charging station configuration with ES

In both the techniques the electric spring can be incorporated to reduce the storage requirements. This means that battery size can be reduced by incorporating the ES configuration.

4.2 In Roof Mounted solar electric vehicles: The advancement in solar generating modules provides the possibility of roof top soar electric vehicles. The only hurdle to carry forward with the system is the availability of required DC voltage and power. Hence, DC-DC converters are required to convert low DC voltage from solar module to a higher level. Then the high voltage DC must be inverted to provide supply to compressors, temperature control modules and other accessories in the vehicles which requires AC. An Ultra-High-Voltage Gain DC-DC Converter for Roof-mounted Solar Cells Electric Vehicle is presented in [44]. So, the concept of Electric Spring can also be implemented in roof mounted solar electric vehicles. The block diagram for the proposed system is shown in Fig. 4.

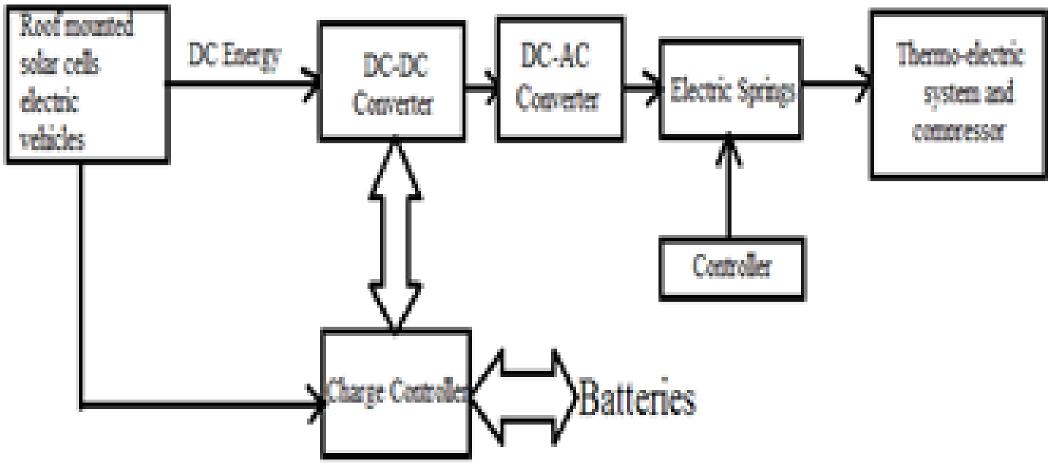

Fig. 4. Block diagram of Roof mounted solar vehicle with ES system

The implementation of ES at source side in roof mounted solar vehicle is shown in Fig. 5.

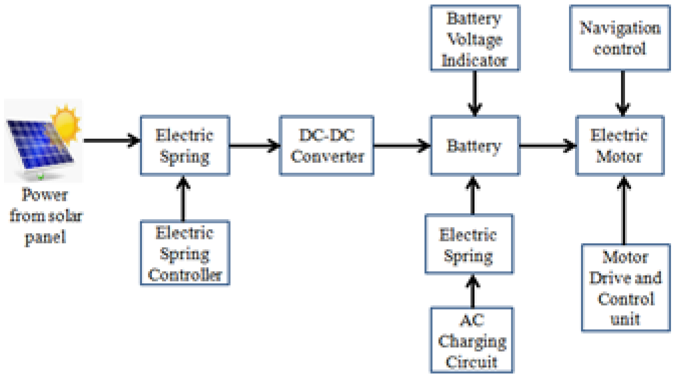

Fig. 5. Block diagram of Roof mounted solar vehicle with ES incorporated at panel side

5. REACTIVE POWER COMPENSATION

Electrical energy is generated, transmitted, distributed and utilized among the consumers in alternating current (ac) only except in rare cases. To supply reactive power along with the active power is one of the major necessities of alternating current. Since we know that reactive power is either consumed or generated in almost every part of the system like at generation, transmission, and distribution and at loads. The problem of reactive power compensation is related or associated with load and voltage support. So the compensation of reactive power is either by supplying or by consuming. There are major advantages provided by the proposed technology as electric springs been proven in all the aspects as addressed in this context. Electric spring played a key role in reducing the energy storage requirements in smart grid and the details were also presented in [45]. The paper presented the concept as how the demand profile of non-critical load follow profile of power generation by reducing the instantaneous power imbalance of power supply and demand. This leads to the reduction in the energy storage requirements.

6. CONCLUSION

This paper provides an overview of utilization of electric spring in EV system that can be a prominent option for providing voltage and power stability in EV integration with power grid. The implementation of electric spring at charging stations and roof mounted solar powered electric vehicles is also reviewed in this paper. The problems at charging stations either AC charging or DC charging can be addressed with EV-ES integration which provides a suitable solution for that. The store requirements can also be reduced by EV-ES integration system.

7. REFERENCES

1. G. Rizzo, I. Arsie, M. Sorrentino, "Hybrid Solar Vehicles,"in Solar Collectors and Panels, Theory and Applications, Dr. Reccab Manyala, Ed., InTech, 2010, ch. 4, pp. 79–96. [Online] Available: http://www.intechopen.com/books/solar-collectors-andpanels–theory-and-applications/hybrid-solar-vehicles.
2. P. Varaiya, F. Wu, and J. Bialek, "Smart operation of smart grid: Risklimiting dispatch," Proc. IEEE, vol. 99, no. 1 , pp. 40–57, 2011.
3. Koutsopoulos and L. Tassiulas, "Challenges in demand load control for the smart grid," IEEE Netw., vol. 25, no. 5 , pp. 16–21, 2011.
4. Zhang,Yu., et al. "Research of voltage stability analysis method in distribution power system with plug-in electric vehicle", Asia-Pacific Power and Energy Engineering Conference (APPEEC), IEEE, 2016.
5. R. Walling, R. Saint, R. Dugan, J. Burke, and L. Kojovic, "Summary of distributed resources impact on power delivery systems," IEEE Trans. Power Del., vol. 23, no. 3, pp. 1636–1644, Jul. 2008.
6. K. Clement-Nyns, E. Haesen, and J. Driesen, "The impact of vehicle to-grid on the distribution grid," Electr. Power Syst. Res., vol. 81, no. 1,pp. 185–192, Jan. 2011.
7. Z. Luo, Z. Hu, Y. Song, Z. Xu, and H. Lu, "Optimal coordination of plug-in electric vehicles in power grids with cost-benefit analysis part I: Enabling techniques," IEEE Trans. Power Syst., vol. 28, no. 4, pp. 3546–3555, Nov. 2013.
8. D. Manz et al., "The grid of the future: Ten trends that will shape the grid over the next decade," IEEE Power Energy Mag., vol. 12, no. 3, pp. 26–36, May 2014.
9. M. Gray andW. Morsi, "Power quality assessment in distribution systems embedded with plug-in hybrid and battery electric vehicles," IEEE Trans. Power Syst., vol. 30, no. 2, pp. 663–671, Mar. 2015.
10. S. Y. R. Hui, C. K. Lee, and F. F. Wu, "Electric springs — a new smart grid technology," IEEE Trans. Smart Grid, vol. 3, no. 3, pp. 552–1561, Sep. 2012.
11. M. Prudente, L. L. Pfitscher, G. Emmendoerfer, E. F. Romaneli, and R. Gules, "Voltage multiplier cells applied to
12. non-isolated dc-dc converters," IEEE Trans. Power Electron., vol. 23, no. 2, pp. 871-887, Mar. 2008.
13. Ioinovici, "Switched-capacitor power electronics circuits," IEEE Circuits Syst. Mag., vol. 1, no. 3, pp. 37–42,
14. Mar. 2001.
15. Y. Berkovich and A. Ioinovici, "Switched capacitor/switched-inductor structures for getting transformer less hybrid dc-dc PWM converters," IEEE Trans. Circuits Syst. I, Fundam. Theory Appl., vol. 55, no. 2, pp. 687-696, Mar. 2008.
16. M. Zhu, T. Wang, and F. L. Luo, "Analysis of voltage-lifttype boost converters," in Proc. 7th. IEEE Ind. Electron.
17. Applicat. Conf., Melbourne, Australia, pp. 214-219, Jul. 2012.
18. R. J. Wai, C. Y. Lin, R. Y. Duan, and Y. R. Chang, "High efficiency dc-dc converter with high voltage gain and reduced switch stress," IEEE Trans. Ind. Electron., vol. 54, no. 1, pp. 354-364, Jan. 2007.
19. G. Zhang, B. Zhang, Z. Li, D. Qiu, L. Yang, and W. A. Halang, "A 3-Z-network boost converter," IEEE Trans. Ind.
20. Electron, vol. 62, no. 1, pp. 278-288, Jan. 2015.
21. F. Z. Peng, "Z-source inverter," IEEE Trans. Ind. Appl., vol. 39, no. 2, pp. 504-510, Mar./Apr. 2003.
22. W. Kempton and S. E. Letendre, "Electric vehicles as a new power source for electric utilities," Transp. Res., vol. 2, no. 3, pp. 157–175, 1997.
23. Z. Luo, Z. Hu, Y. Song, Z. Xu, and H. Lu, "Optimal coordination of plug-in electric vehicles in power grids with cost-benefit analysis part II: A case study in China," IEEE Trans. Power Syst., vol. 28, no. 4, pp. 3556–3565, Nov. 2013.
24. M. C. Kisacikoglu, B. Ozpineci, and L. M. Tolbert, "EV/PHEV bidirectional charger assessment for V2G reactive power operation," IEEE Trans. Power Electron., vol. 28, no. 12, pp. 5717–5727, Dec. 2013.

25. M. Falahi, H.-M. Chou, M. Ehsani, L. Xie, and K. Butler-Purry, "Potential power quality benefits of electric vehicles," IEEE Trans. Sustain. Energy, vol. 4, no. 4, pp. 1016–1023, Oct. 2013.
26. J. G. Pinto, V. Monteiro, H. Goncalves, and J. L. Afonso, "On-board reconfigurable battery charger for electric vehicles with traction-to-auxiliary model," IEEE Trans. Veh. Technol., vol. 63, no. 3, pp. 1104–1116, Mar. 2014.
27. T. Tanaka, T. Sekiya, H. Tanaka, M. Okamoto, and E. Hiraki, "Smart charger for electric vehicles with power-quality compensator on single phase three-wire distribution feeders," IEEE Trans. Ind. Appl., vol. 49, no. 6, pp. 2628–2635, Nov./Dec. 2013.
28. R. Ferreira, L. Miranda, R. Araujo, and J. Lopes, "A new bi-directional charger for vehicle-to-grid integration," in Proc. 2nd IEEE PES Int. Conf. Exhibit. Innov. Smart Grid Technol., Manchester, U.K., Dec. 2011, pp. 1–5.
29. P. Sauer, "Reactive power and voltage control issues in electric power systems," Appl. Math. Restructured Elect. Power Syst., pp. 11–24, 2005.
30. Y. Rong, C. Li, H. Tang, and X. Zheng, "Output feedback control of single-phase UPQC based on a novel model," IEEE Trans. Power Del., vol. 24, no. 3 , pp. 1586–1597, 2009.
31. H. Fujita, Y. Watanabe, and H. Akagi, "Control and analysis of a unified power flow controller," IEEE Trans. Power Electron., vol. 14, no. 6 , pp. 1021–1027, 1999.
32. K. Sen and E. J. Stacey, "UPFC-unified power flow controller: theory, modeling, and applications," IEEE Trans. Power Del., vol. 13, no. 4 , pp. 1453–1460, 1998.
33. S. Kannan, S. Jayaram, andM. Salama, "Real and reactive power coordination for a unified power low controller," IEEE Trans. Power Syst., vol. 19, no. 3 , pp. 1454–1461, 2004.
34. Y. Kim, J. S. Kim, and S. H. Ko, "Three-phase three-wire series active power filter, which compensates for harmonics and reactive power," IEE Proc.—Elect. Power Appl., vol. 151, no. 3 , pp. 276–282, 2004.
35. C. K. Lee, Hui, and S. Y. R. Hui, "Reduction of energy storage requirements in future smart grid using electric springs," IEEE Transaction on Smart Grid, vol. , no. 99, pp. 1-7, Apr. 2013.
36. M. Parvania and M. Fotuhi-Firuzabad, "Demand response scheduling by stochastic SCUC," IEEE Transactions on Smart Grid, vol. 1, no. 1, pp. 89–98, Jun. 2010.
37. M. Pedrasa, T. D. Spooner, and I. F. MacGill, "Scheduling of demand side resources using binary particle swarm optimization," IEEE Transactions on Power Systems, vol. 24, no. 3, pp. 1173–1181, Aug. 2009.
38. J. Conejo, J. M. Morales, and L. Baringo, "Real-time demand response model," IEEE Transactions on Smart Grid, vol. 1, no. 3, pp. 236–242, Dec.2010.
39. J. Roscoe and G. Ault, "Supporting high penetrations of renewable generation via implementation of real-time electricity pricing and demand response," IET Renewable Power Generation, vol. 4, no. 4, pp. 369–382, Jul. 2010.
40. P. Palensky and D. Dietrich, "Demand side management: demand response, intelligent energy systems, and smart loads," IEEE Transactions on Industrial Informatics, vol. 7, no. 3, pp. 381–388, Aug. 2011.
41. Mohsenian-Rad, V. W. S. Wong, J. Jatskevich, R. Schober, and A. Leon-Garcia, "Autonomous demand-side management based on game theoretic energy consumption scheduling for the future smart grid," IEEE Transactions on Smart Grid, vol. 1, no. 3, pp. 320–331, Dec. 2010.
42. Mohd, E. Ortjohann, and A. Schmelter, "Challenges in integrating distributed energy storage systems into future smart grid," IEEE Symposium on Industrial Electronics, pp. 1627-1632, 2008
43. J. A. McDowall, "Status and outlook of the energy storage market," PES 2007, Tampa, July 2007.
44. Ghanim Putrus, P. Suwanapingkarl, D. Johnston, E.C. Bentley, "Impact of electric vehicles on power distribution networks", IEE Conference on Vehicle Power and Propulsion Conference, oct. 2009
45. Julian de Hoog; Doreen A. Thomas; Valentin Muenzel; Derek C. Jayasuriya; Tansu Alpcan; Marcus Brazil; Iven Mareels, "Electric vehicle charging and grid constraints: Comparing distributed and centralized approaches", IEE Power & Energy Society General Meeting, Nov. 2013.
46. Ciprian Vlad, Gabriel Murariu, "Using Renewable ebergy sources for electric vehicles charging", IEEE 2013.
47. Mehmet Cem Catalbas, Merve Yildirim, Arif Gultan and Hasn Kurum, "Estimation of optimal location for Electric Vehicles charging stations", IEEE 2017.
48. Yu Z. H, Zeng J., Liu J. F, "An Ultra-High-Voltage Gain DC-DC Converter for Roof-mounted Solar Cells Electric Vehicle", International Conference on Power Electronics Systems and Applications - Smart Mobility, Power Transfer & Security (PESA), 2017
49. Chi Kwan Lee, Shu Yuen (Ron) Hui, "Reduction of energy storage requirements in future smart grids", IEEE Transactions on Smart Grid, Vol. 4, No. 3, September 2013