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# EXTREME FAST CHARGING OF ELECTRIC VEHICLE BY USING SOLID STATE TRANSFFORMER

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## ABSTRACT:

Transportation electrification is one of the most trending research projectsfor the past two decades. It reduces the CO2 emissions and conserve the rapidly declining fossil reserves. In this regard, Electric vehicles (EV) based on battery energy storage are gaining widespread popularity as a means to replace the conventional lesser efficient internal combustion engines (ICE).Electric vehicle (EV) technology has gained popularity due to its higher efficiency, less maintenance, and lower dependence on fossil fuels. However, a longer charging time is a significant barrier to its complete adaptation. Solid state transformer (SST) based extreme fast charging emerged as an interesting idea with an ability to provide arefuellingcapability analogous to that of gasoline vehicles. At first, the key barriers of using a traditional low frequency transformer (LFT) are discussed, and potential solutions are suggested by replacing the conventional LFT with high frequency SST at extreme fast-charging (XFC) stations. Then, various SST-based converter and their control for EV fast-charging stations are described. Furthermore, the realization of SST for EV charging is comprehensively discussed, which facilitates understanding the current challenges and technologies.

## 1.1 INTRODUCTION:

Transportation is one of the importantsectorsthat has a major role in today's world. Fossil fuels are the main source for many vehicles which leads to the air pollution and cause global warming and greenhouse effect. Pollution free environment is necessary. Electric Vehicles (EVs) are becoming most popular alternative to gasoline powered (ICE) vehicles in order to reduce greenhouse gases and mitigate air pollution.Unavailability of efficient EV charging infrastructure is one of the prominent limiting factors for faster adoption of EVs. Electric cables with high power density and bulky cables are used to charge almost all of the existing

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EVs.so, to charge the EVs fast we are introducing the concept extreme fast charging by using solid -state transformer (SST).

The state-of-the-art dc fast chargers and present the motivation for and the advantages of grouping dc fast chargers into extreme fast charging (XFC) stations. We review power electronics converters suitable for XFC stations, specifically focusing on AC/DC front-end stage design and isolated and non-isolated DC/DC converter topologies and their applications that satisfy the isolation requirements for automotive traction batteries. Further, we assess the benefits of replacing the conventional linefrequency transformer with the solid-state transformer (SST) in the XFC stations to convert the medium voltage (MV) to low voltage (LV) and provide galvanic isolation. The SST topologies for the XFC application are explained.

## 1.2 NEED OF EXTREME FAST CHARGING

In future the fossil fuels like coal, petrol, diesel will vanish because these are the non-renewable sources of energy. The transportation system will have limitations in future. Therefore, we go for the electric vehicle for transportation purpose. Because of existing gasoline and petrol engine technology vehicles greenhouse gases are increases. Plug-in Electric Vehicles are implemented to achieve environmentfriendly transportation and reduced some extent of greenhouse gas. The usage of PEV is currently increased but there are some battery related problems such as slower charging rate, low energy storage capacity, size, and weight. A new technology is required to reduced battery related problems and for development of EVs. Due to charging related issues affected the faster growth of PEVs. To reduce battery related problems, greenhouse gases and to resolving the charging timeproblem the concept of Extreme Fast Charging (XFC) system is developed. Many charging stations are built up on the side of road, since the users travel further distance by recharging their electric vehicle.

Due to their relatively low power rating, these on-board chargers are suitable for overnight charging. The limited power ratings of on-board chargers hasled to the development of dc fast chargers, typically rated at 50 kW and, more recently, at power levels up to 350 kW. These chargers deliver dc power to the vehicle battery via an isolated power converter located outside the vehicle, and they have the potential to provide EV users with satisfactory charging speed

## 1.3 ISSUES AND SOLUTIONS

The major issues to be considered in Extreme Fast charging methods includes:

- Size and weight of the cable.
- Peak demand of load.
- High power usage increases challenges and cost.
- Storage of energy.
- Standard range of convertors for power conversion.
- Heat will be generated a lot.

There are some solutions that can be provided to overcome these issues is possible through the following methods.One way to reduce the cable weight and deliver more power to the vehicle is to transfer power at higher voltage levels. For 800 V voltage level, the cable weight limits the charging power to be lower than 350 kW. Cable liquid cooling is one potential solution that can effectively reduce the thermal stress on the cable, making smaller and lighter cable feasible for XFC.Integrating Renewable Energy Sources(RES) and exploiting V2G technology not only adds generation to the station and mitigates demand charges, but also enables profiling the power exchange between the charging station and the grid and therefore provides ancillary services to the grid including load shifting and frequency regulation.

Another possible method to mitigate the power demand and reduce the impact of EV charging on the grid is to integrate multiple renewable resources and battery energy storage systems into XFC stations. For example, in the optimal locations and capacities of EV charging stations are determined through a spatial-temporal model of the EV mobility, reducing the planning cost and improving the charger availability

| S.no | References | Description |
|---|---|---|
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| | Member, IEEE, SrdjanSrdic, Senior Member IEEE and Srdjan Lukic, Senior Member, IEEEs Extreme Fast Charging of Electricvehicles:(DOI10.1109/TTE.2019.2958709) | art XFC converter technology for EVs that can address the challenges and utilize the opportunities brought by the increasing penetration of EVs. An emerging trend is to co-locate multiple XFCs to form XFC charging stations and thus reduce the installation cost per charging stall. This paper reviews the state-of-the-art XFC converter technology for EVs that can address the challenges and utilize the opportunities brought by the increasing penetration of EVs. An emerging trend is to co-locate multiple XFCs to form XFC charging stations and thus reduce the installation cost per charging stall. |
| 2. | YAMEENA Tahir, Irfan Khan, Syed Rahman, Muhammad Faisal Nadeem, Atif Iqbal, YINLIANG Xu and Mohammad RafiA state-of-the-art review on topologies and control techniques of solid-state transformers for electric vehicle extreme fast charging(DOI: 10.1049/pel2.12141 4 April 2021) | In this paper, comparison of using traditional LFT and HFT is presented. The overall size and cost of SST comparatively less than that LFT of same ratings.by using HFT it reduces the cost, size and increases the efficiency, power quality and voltage regulation. |

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| 3. | XIAYOU Duan, Student Member, IEEE, Zec Hun Hu, Senior Member, IEEE, and Yonghua Song, Fellow, IEEE.s Bidding Strategies in Energy and Reserve Markets for an Aggregator of Multiple EV Fast Charging Stations with Battery Storage IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS 2019. | The paper focuses on EV aggregator of multiple FCS and equipped with ESS.This paper reviews the state-of-the-art XFC converter technology for EVs that can address the challenges and utilize the opportunities brought by the increasing penetration of EVs. An emerging trend is to co-locate multiple XFCs to form XFC charging stations and thus reduce the installation cost per charging stall. |
| 4. | Vishnu Mahadeva Iyer, Student Member, Srinivas Gular, Student Member, Ghanshyam's Gohil, Member, and Subhashish Bhattacharya, Senior MemberAnApproach Towards Extreme Fast Charging Station Power Delivery for Electric Vehicles with Partial Power Processing (978-1-5386-1180-7/18/$31.00 2018 IEEE. | This paper,approach towards a power delivery architecture for an XFC station that makes use of multiple partial power charging units (PPCUs) is proposed in this paper. System level benefits of using the proposed power delivery scheme include lower capital investments, lower operational costs and improved power and energy efficiency. |
| 5. | CHENGCHENG Shao Member, IEEE, Tao Qian Yanan Wang, and Xifan Wang, Life Fellow, IEEECoordinated Planning of Extreme Fast Charging Stations and Power Distribution Networks. Considering On-Site Storage. | The XFC technology provides an efficient way to improve user charging experience and promote the EV penetration. However, it would impose great challenges on the power grid. In this paper, a coordinated planning model has |

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| | | been proposed for power distribution networks with XFC station considered |
| 6. | LIRAN Zheng, Rajendra Prasad Kandula, Deepak Divan, Center for Distributed EnergyMultiport Power Management Method with Partial Power Processing in a MV Solid-State Transformer for PV, Storage, and Fast-Charging EV Integration (978-1-7281-5826-6/20/$31.00 2020 IEEE.) | This paper presents a multiport power management method with partial-power processing capability for a three-port solid state transformer to improve its efficiency. Applications of the multiport SST with partial-power processing include PV and storage integration into the grid and EV fast charging stations. |
| 7. | Xu. She, Student Member, IEEE, Rolando Burgos, Member, IEEE, Gangyao Wang1Student Member, IEEE and Alex Q. Huang1 Fellow, IEEE Review of Solid-State Transformer in the Distribution System: From Components to Field Application. (2019, 12, 3721; doi:10.3390/en12193721) | This paper has presented a comprehensive technology review of the SST, from component design to system application, aiming at providing a systematic review in this area. However, since the utilization of power converters in transmission and distribution is still relatively low, the electric power grid remains one of the next major frontiers where to introduce large scale power electronics technology |
| 8. | Deepak Ronanki, Apoorva Kelkar, Sheldon S. Williamson Review of Solid-State Transformer in the Distribution System Extreme Fast Charging Technology—Prospects to Enhance Sustainable Electric Transportation. (978-1-4673-0803-8/12/$31.00 2012 IEEE.) | This paper presents an overview of the challenges and opportunities of XFCs using SST technology to facilitate the next step for future charging solutions for future generation of EVs. It can be |

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| | | concluded that with the evolution of new power conversion topologies. However, operation, design and control of XFC stations must be addressed properly without affecting the stability of the grid |
| 9. | Vishnu Mahadeva Iyer, Srinivas Gulur, Ghanshyamsinh Gohil and Subhashish BhattacharyaExtreme Fast Charging Station Architecture for Electric Vehicles with Partial Power Processing.(DOI 10.1109/TIE.2019.2945264, IEEE) | partial rated dc-dc converters are used to charge the individual EVs. System level benefits of using the proposed power delivery scheme include lower capital investments, lower operational costs and improved power and energy efficiency. The features and requirements of using such a partial rated converter for a battery charging application are discussed and a suitable converter topology is identified for the charger. Global control strategy for the XFC station is discussed. |

## 3.1 CHARGING SYSTEMS FOR ELECTRIC VEHICLES

Charging systems plays a crucial role in development of EVs.As compared to gasoline engine vehicles, EVs require more time for refuelling, have less range dedicated charging connectors and fewer charging stations. An EV charger with high power and with high efficiency is needed to overcome this refuelling problem. Various charging technologies that provide fast charging and increase the driving range are introduced.

### 3.1.1CHARGING PROCESS:

The ac level 1 and ac level 2 on-board chargers take 120 V and 240 V ac input, respectively, delivering a peak power of 1.9 kW and 19.2 kW, respectively. Due to their relatively low power rating, these on-board chargers are suitable for overnight charging. The limited power ratings of on-board chargers haveled to the development of dc fast chargers, typically rated at 50 kW and, more recently, at power levels up to 350 kW. These chargers deliver dc power to the vehicle battery via an isolated power converter located outside the vehicle, and they have the potential to provide EV users with satisfactory charging speed.

The state-of-the-art dc fast chargers convert the three-phase ac voltage up to 480 V to the desired dc voltage by two power electronics conversion stages: an AC/DC rectification stage with power factor correction (PFC), which converts three-phase input ac voltage to an intermediate dc voltage; and a DC/DC stage, which converts the intermediate dc voltage into regulated dc voltage required to charge the electric vehicle.

### 3.1.2 HIGH FREQUENCY TRANSFORMER IN PLACE OF LOW FREQUENCY TRANSFORMER:

The galvanic isolation between the grid and the EV battery can be provided in one of the two following methods. The first option is to use a line-frequency transformer before the AC/DC stage to provide isolation from the grid (See Fig. 1a). The following DC/DC stage is a non-isolated converter. The second option is to exploit a high-frequency transformer inside an isolated DC/DC converter to provide isolation (See Fig. 1b). If a single-module charger does not meet the power requirement of the dc fast charger system, multiple identical modules are connected in parallel to increase the output power as shown in Fig. 1c and Fig. 1d

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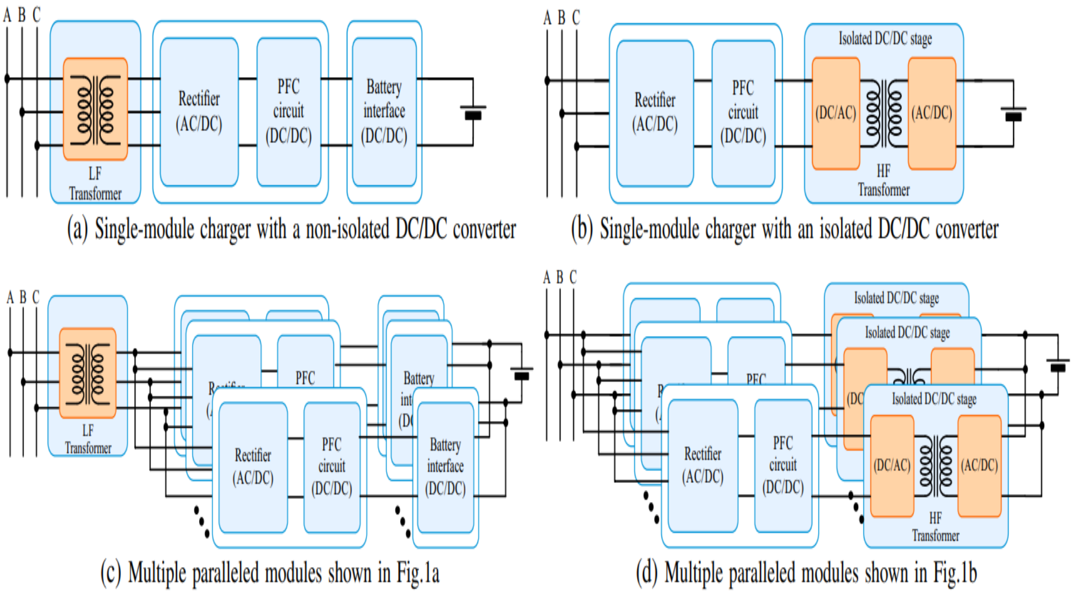


Fig 3.1.2 Simplified block diagram of dc charger power conversion system

## 4.1COMPARISION OF AC AND DC CONNECTED SYSTEM:

For ac-connected systems, a step down-transformer interfaces between the distribution network and a three-phase ac bus operating at 250 V - 480 V line-to-line voltage. The ac bus supplies each charger at the station, and each charger features a separate AC/DC stage. This approach significantly increases the number of conversion stages between the distribution network and the dc port of the EV or the RES (e.g.PV or battery). Having more conversion stages in the ac-connected system increases the system complexity and cost while decreasing the system efficiency. The advantages of using the ac bus include the availability and maturity of the rectifier and inverter technology, availability of ac switchgear and protective devices, and well-established standards and practices for the ac power distribution systems. Further, there are developed standards for EV charging stations. Most state-of-the-art XFC stations are ac-connected systems.

For dc-connected systems, one central front-end AC/DC converter is used to create a dc bus, providing a more energy efficient way of interfacing dc energy storage and renewable energy sources. The central front-end features a low-frequency transformer followed by a LV (250 V - 480 V) rectifier stage, or an SST that provides the rectification, voltage step-down and isolation function in a single unit. To accommodate the state-of-the-art battery voltage range (approximately 400 V), the dc bus voltage is normally less than 1000 V. At this voltage level, the design of the XFC stations with a dc bus should comply with the same standards. Each charger is interfaced to the dc bus with a DC/DC converter, removing the individual AC/DC converters. With a reduced number of conversion stages, the system efficiency is improved compared to that of the ac-connected systems. One potential advantage of the "dc distribution" approach is that there is a single interconnection to the utility though the central front-end. This provides an opportunity to exploit the load diversification resulting from varying EV battery capacities and changing charge acceptance of the battery as a function of the SOC to significantly de-rate the AC/DC converter and the nameplate of the grid connection, thus reducing system installation cost. Other advantages of DC systems include the absence of reactive power in dc system.

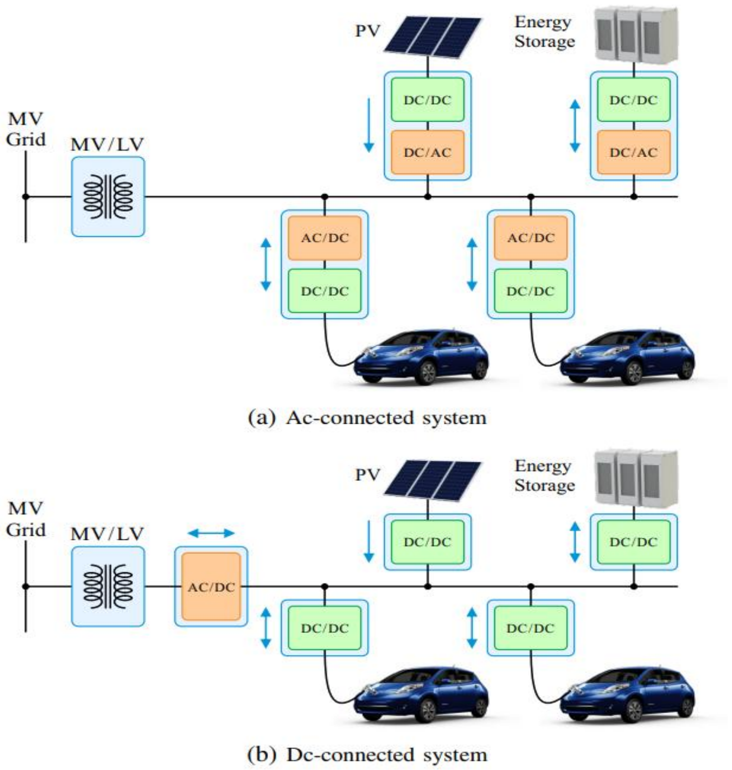


Fig.4.1 (a)Configurations for XFC stations

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TABLE IV: Comparison of AC-connected and DC-connected systems

| | Ac-connected | Dc-connected |
|---|---|---|
| Conversion stages | More | Less |
| Efficiency | Lower | Higher |
| front-end de-rating | No | Yes |
| Control | Complex | Simple |
| Protection | Straightforward | Complex |
| Metering | Standardized | Non-standardized |

The state-of-the-art fast charging stations are supplied form three-phase low-voltage distribution grid, using up to 480 V line-to-line (depending on the region) as an input. This voltage is typically generated by a dedicated MV-to-LV service transformer. The bulky service transformer increases the size and cost of the system while adding complexity to the installation. To eliminate the need of the MV-to-LV transformer, a power electronics based solid-state transformer (SST) can be used to interface the MV grid directly. The term solid-state transformer (SST) has been loosely used to refer to the concept of replacing line-frequency transformers with power electronics converters that provide voltage conversion and galvanic isolation using high-frequency transformers. Compared to the traditional linefrequency transformer, the SST has a number of unique features such as better controllability, current limiting capabilities, and higher efficiency at light load


Fig .4.1(b) dc fast charging station vs SST based charging station

## 4.2 SST BASED MEDIUM VOLTAGE EXTREME FAST CHARGERS:

1) SSTs commonly use identical modules as building blocks to reach the desired voltage and power levels. To interface to the MV grid directly, the modules are connected in series at the input to increase the voltage blocking capability while the outputs of the modules are

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connected in parallel to provide large output current at the desired low dc voltage. Three modules are connected in series at the MV ac side (2.4 kV) and in parallel at the battery side. Each module has aunidirectional NPC AC/DC front-end to realize AC/DC conversion and power factor correction. The system efficiency is close to 96%.

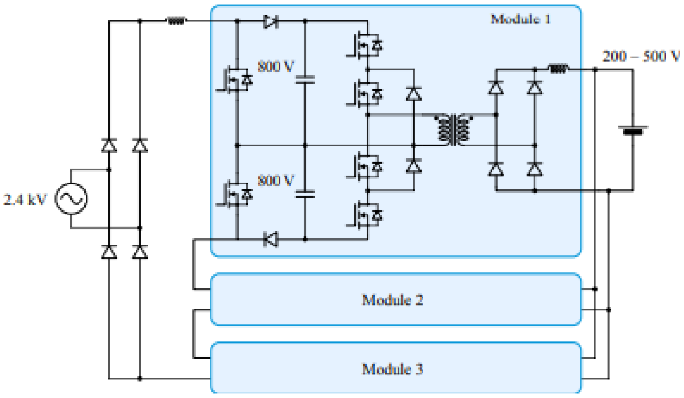


Fig.4.2(a) MV fast charger topology developed by EPRI

2)Eight modules are connected in series at the MV side to share 8 kV ac voltage. The AC/DC front-end of each module has an uncontrolled diode bridge rectifier followed by twounidirectional three-level boost converter phase legs in parallel. The internal bus is 1.4 kV. The DC/DC stage is two input-series-outputparallel half-bridge LLC converters capable of soft-switching. To achieve high efficiency, the LLC converters operate in open loop with 100% duty cycle. The system efficiency is 97.5% at rated load.

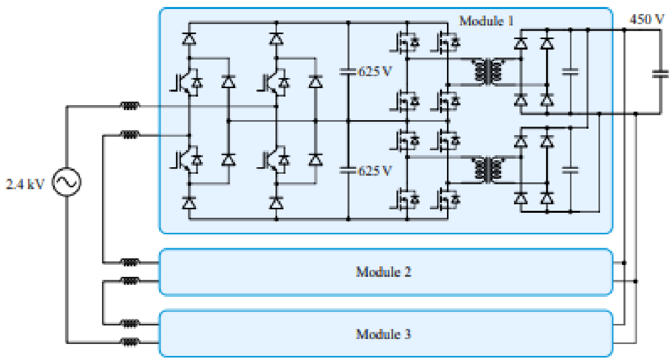


Fig.4.2(b) MV fast charger topology developed by Virginia Tech

3)Three modules are connected in series at the MV side to share 2.4 kV ac voltage. Instead of having a diode bridge for each module as in the design in Fig. 8b, a single diode bridge is used to rectify the MV ac input. This reduces the forward voltage drop on diodes and improves the efficiency. Each module has three-level boost converter for power factor correction. The following DC/DC stage consists of a half-bridge NPC converter, a high-frequency transformer and a diode bridge rectifier. The use of the half-bridge NPC converter in the DC/DC stage further reduces the size of the high-frequency transformer. The system efficiency is higher than 97.5% at 50 kW

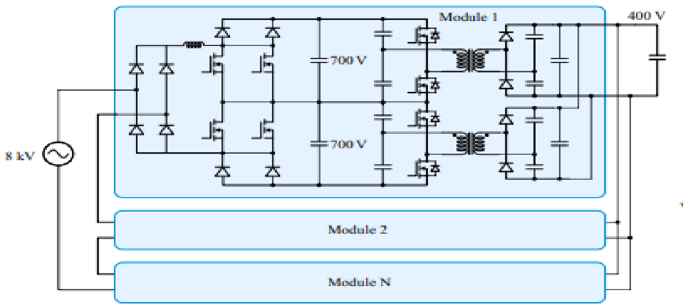


Fig.4.2(C) MV fast charger topology developed by North Carolina State University

4)a full-bridge AC/DC front-end and a dual half-bridge converter in the DC/DC stage. To integrate energy storage into the charging station, a non-isolated boost converter is added between the AC/DC front-end and the DC/DC stage. Compared with the previous converters, this converter is capable of bidirectional power flow but uses more active switches, which results in poor switch utilization and low efficiency. Also, the control is more complex than that of the unidirectional converters. The converter is verified with 3.6 kV input and the reported efficiency is less than 92%.

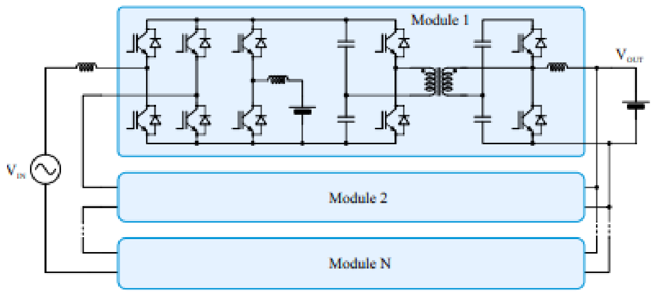


Fig.4.2(d) MV fast charger another topology

5)Another SST implementation led by Delta Electronics aims at building a three-phase SST-Based 400 kW XFC connected to 4.8 kV or 13.2 kV MV grid [144]. The proposed topology is shown in Fig. 8e. Each module is rated at 15 kW with 1 kV ac input voltage. Considering line-to-neutral voltage, three modules are connected in series for 4.8 kV and nine modules for 13.2 kV grid. The efficiency of a single module is 97.3% measured at 15 kW and 1 kV ac input

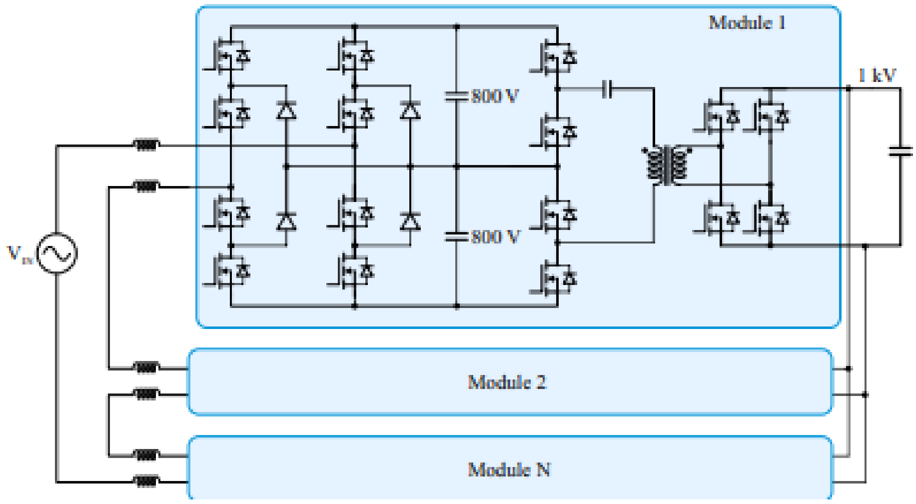


Fig.4.2(e) MV fast charger topology developed by Delta Electronics

## CONCLUSION

Increasing number of EVs on the road, the lack of charging infrastructure and long charging times restrict the use of these vehicles to daily commutes and short distance trips. To address this problem, there is a need for a cost-effective and ubiquitous charging infrastructure that can compete with the existing gasoline-powered vehicle refuelling infrastructure. This paper reviews the state-of-the-art XFC converter technology for EVs that can address the challenges and utilize the opportunities brought by the increasing penetration of EVs. An emerging trend is to co-locate multiple XFCs to form XFC charging stations and thus reduce the installation cost per charging stall. By exploiting the load diversification resulting from different EV battery capacities and different charge acceptance a function of the battery SOC, the installation and operation cost can be reduced, bringing benefits to the station owner and EV users. Energy storage and RES are integrated as part of the charging stations as a common method to reduce high-demand charges that are incurred during peak power hours.

Two different distribution methods for XFC stations are presented. While the ac distribution method is a mature solution with available components and well-established standards, the dc distribution method presents the potential of achieving lower cost and higher efficiency. The suitable power electronics converters for both methods are reviewed and compared.While the state-of-the-art dc fast chargers requires MV-toLV line-frequency transformers, another solution is the SSTbased dc fast charger that provides rectification, voltage stepdown, and isolation function in a single unit. The SST-based XFCs provide size reduction and efficiency improvement over the state-of-the-art implementations, which can in turn reduce the installation costs by allowing more power delivery on the same station footprint and maximize operating profit by minimizing the power lost in the conversion process.

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