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Impact of Energy Management of Electric Vehicles on Transient Voltage Stability of Microgrid

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Abstract

There is cause and effect relationship between increase in load due to increasing penetration of electric vehicles (EV) load that causes unbalanced conditions and affect the power quality such as voltage degradation and even damage the equipment if the system is not properly managed. This paper presents detailed review of energy supply and management in conjunction with load synchronization through EVs for maintaining transient voltage stability by providing reactive power support for the stability of power grid in vehicle-to-grid mode of operations. The energy management system is considered at different levels such as, stand-alone PV, stand-alone wind, stand-alone battery storage, stand-alone EV parking lot, residential feeder and commercial building feeders. First we proposed energy management algorithm, to limit the peak power drawn by EVs from distributed energy resources of microgrid, such that additional electrical resource will be transferred to resource constrained devices. The EVs negotiate based on their demand, priority and available electrical resource such that during higher electricity price the higher priority vehicles still require resource and perform uninterrupted operation. The transfer of electrical resource from one load device to another will help in reducing peak demand and improving the efficiency of the system. Secondly we proposed transient voltage stability margin index (TVSMI) to test the capability of EVs in contributing storage and supply services to the grid. The energy management control simulations are realized in DIgSILENT Power factory.

Keywords: distribution network reliability, energy management system, vehicle-to-grid (V2G), ancillary services

1 Introduction

Taking the lead from advanced control and communication technologies, EVs have been developed and marketed since the end of the 19th century. Energy scarcity and environmental pollution has compelled researchers to develop efficient, environmental-friendly EVs along with the advancement in the clean energy technology [1]. Currently, the penetration of EVs is less than the expected but in near future penetration of EVs is expected to rise. Moreover it is expected that there will be more and more induction motor loads connected to the power grid. The motor loads are random and have fluctuations in the characteristics which have significance impact on grid security [2]. Hence, with the increase in non-linear load the power system optimization control, power quality maintenance and distribution network planning become more difficult. The grid security and stability studies are accomplished to assess the impact of induction motor load growth in terms of grid voltage loss, harmonics and load imbalances and its mitigation using EVs as a provision of ancillary services, such as reactive power compensation, the load support and the frequency tuning [3-5]. EVs can act a special kind of load and source, which can be supplied power from the grid for charging and take back power when necessary [6]. EVs as mobile storage unit act like a source to provide reactive power compensation in order to improve the grid stability and security [7]. Therefore it has important theoretical and practical significance to study the transient voltage stability of distribution network which may be improved by V2G mode of operation.

In recent decades, many researchers proposed provision of ancillary services through EVs in distributed fashion which help in improving the stability and reliability of the stressed system. Like, distributed control provides local compensation in order to damp the low frequency oscillation using power system stabilizers (PSS). Local measurements of dynamic disturbance provide efficient best quality response. The use of distributed control in multiple adjacent areas may lead towards adverse situation, hence the global control can provide better control and is necessary [8, 9]. Similar to wide-area controllers (WACs) microgrid energy supply and management system (ESMS) use the distributed energy management services using IEEE 802.11 Wi-MAX [10]. The ESMS has the capability to transmit and receive the information. The transmission of control signal is based on predefined objective function for the enhancement of performance of dynamic system [11].

Numerous researchers have contributed in the area of intelligent systems and autonomous agents, such as [12] uses a general case of using agent in control systems, [13] motivates the uses of agents at different control levels e.g. feeder and load agents. Whereas, in [14] the multiagent mechanism for islanding operation is depicted. Wide area signal based intelligent control for FACTS have been presented in [15]. Most of the studies mentioned until now have focused traditional power system and a very few of them have focused the renewable sources but 1) the effects of G2V and V2G the case of EVs for the improving the stability of the power system, 2) taking motor load into consideration to analyse the transient stability of the power system, 3) load synchronization for steady state response of the system and 4) the role of energy supply and management system in improving the stability of the system is not stated yet.

In this study, 1) the impact of charging of EV and discharging of EV (connected to a CERTS microgrid) for the improvement of transient voltage stability of the microgrid in grid connected and islanded mode is presented. 2) An energy management algorithm is developed to balance the load among different types of loads at demand side in microgrid such that additional electrical resource will be transferred to resource constrained devices.

The energy management control is implemented in DIgSILENT Powerfactory. The results with and without energy management system for moderate disturbance due to the start of the motor load like a unexpected discharging of EV and also during volatile situation for example unexpected alteration from discharging to charging mode or during fault, analysis are presented. The analysis confirms that when the EVs are connected to the power system and the use of energy management system improves the stability of the system considerably.

The primary contributions of this study are;

- Development of energy management simulation model.
- Analysis on the impacts of EV operations on the stability of the system.
- The scheme of energy management control for improving the stability of an integrated power system.

The paper has six sections and organized as follows: Section 2 describes the simulation model of CERTS microgrid/ power distribution network architecture. Section 3 illustrates the load synchronization algorithm; Section 4 indicates the the co-simulation platform for energy management system, Section 5 explains a case study and simulation analysis and results, and the last Section 6 shows the conclusion and future research directions.

2 Network architecture

Simulations are performed for the CERTS microgrid presented in Figure 1. There are four radial feeders A, B, C, and D. Static switch and microsource are important components of CERTS microgrid. Static switch is delegated for disconnection if there is disturbance in the power grid within in a short time period. [16] and reconnection as disturbance is no longer present. The microgrid has the capability to reconfigure in an event of fault through backup lines. The backup lines are normally disconnected during normal operation. [17].

Feeder A contains residential subscriber loads containing ordinary loads (about 50% induction motor load), static loads and charging pile for charging of EVs. Charging pile is suitable for charging of EVs at small scale at slow charging rate, while feeder B, feeder C, and feeder D are commercial building subscriber loads which contain less-sensitive loads (about 65% induction motor load) and static loads, ordinary loads (about 50% induction motor load) and static loads, and sensitive loads (about 75% induction motor load), static loads and charging station for the charging of EVs. Charging stations are suitable for charging of EVs at large scale, having the capability of quick charging.

Switch power plant is deployed at the medium voltage bus bar which has the capability to accommodate bulk of EV for quick charging. The charging pile, charging station and switch power plant contains power electronics devices that can interface the EVs to the power grid. The converter has dual functions, for charging the battery it configure itself as diode bridge rectifier and for feeding power from vehicle to gird it configure itself as switch-mode converter in regeneration mode [18]. Thus EV can contribute to the transient voltage stability through storage and supply services.

Stand-alone PV, Wind and battery storage are also connected to the medium voltage bus bar. Whereas, stand-alone battery storage is important to provide transient stability in islanding mode, stand-alone PV modules and wind power to get benefits of renewable energy and synchronous generators necessary for stable operation of microgrid in islanded mode. Batteries and synchronous generators are the two types of sources which may use the droop control for normal operations.

The sensitive loads have high power quality requirment and supplied through synchronous generator, while less-sensitive loads have not have very high power quality requirement and are supplied by through synchronous generators and renewable energy sources like photovoltaic system (PV) etc. The ordinary loads can be switched off in the event of fault, they may or may not have the local generation. Moreover sensitive and less sensitive loads are controllable loads while the ordinary loads are non-controllable loads. The non-controllable loads are supplied from the power commands through the load profile of grid, while the controllable loads are supplied from the power commands through the load profile of DERs in micogrid using ESMS [17].

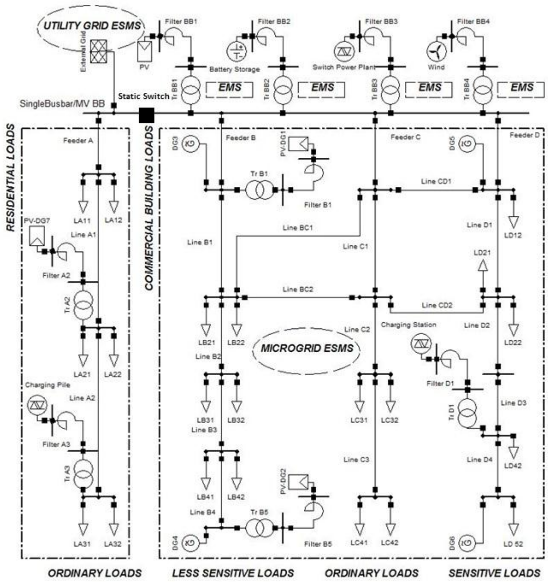

Figure 1: Network architecture.

Controllable and non-controllable loads are further classified as shiftable and non-shifable loads. Where, shiftable loads follow the smart pricing provided by the power grid/microgrid ESMS and non-shiftable loads cannot follow power grid/microgrid ESMS. In the context of shiftable and non-shiftable loads, loads of different characteristics are available. For example;

Simple timed loads, which are shiftable loads. The user can specify their run time and power rating. The time can be chosen by ESMS or by the user.

Setpoint based operating loads, which are non-shiftable loads. The user or the ESMS can specify the setpoint that the device must meet.

Dynamic loads are shiftable loads. These loads can be activated multiple times at different instances during a day or multiple loads can be activated together at the same instance of time like electrical vehicles (EV). In our microgrid EV does stand for a single vehicle and any number of charging instances also. The important parameters of EV charging are given in Table 1.

Table 1: Parameters of EV charging

Nissan -LEAF (EV)		
Battery Capacity	E_{cap}	24kWh
Final SOC	E_{final}	E_{max}
Minimum SOC	E_{min}	30%
Maximum SOC	E_{max}	80%
EV Plug-in Time ($T_{Initial}$)	$T_{re\text{-}charge}$	11 pm
EV Plug-out Time (T_{Final})	$T_{charged}$	7 am
Intitial SOC	$E_{intitial}$	40%
Charger Rating	$P_{chargwe}$	3.0kW
Vehicle to Grid Rating	P_{V2G}	0 kW
Delay Time Setting		12 am
Co-efficient to Reduce Peak Power	R_t	0.0004

The ESMS is not only connected to the power grid/microgrid DERs but also with a combination of fixed WiMAX and LAN. The ESMS of each unit has the capability to communicate with each other, as well as between the central microgrid EMS and other EMS units within in the microgrid. In the next sub-sections we discuss the mathematical modeling of wind turbine generator, photovoltaic cell, battery storage, diesel generator, induction motor and EV charging.

2.1 Wind turbine generator model

Power output of wind turbines depends on wind speed. Mechanical energy is converted into electrical energy, the relationship between wind speed and the wind turbine output power P_{wt} is expressed in term of the following functions given in Equation 1;

$$P_{wt}(t) = \begin{cases} 0 & v \le v_{in} \\ P_{WT}\dfrac{v - v_{in}}{v_r - v_{in}} & v_{in} < v \le v_r \\ P_{WT} & v_r < v \le v_{out} \\ 0 & v > v_{out} \end{cases} \qquad (1)$$

Where P_{WT} stands for the wind turbine rated power, v_{in} stands for the cut-in speed, v_r stands for the rated wind speed and v_{out} stands for the cut-out wind speed. Relationship between the output power and wind speed is represented by Figure 2.

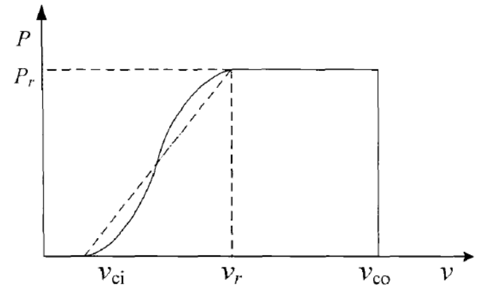

Figure 2: Wind generator active power output curve

2.2 Photovoltaic cell model

The output power of photovoltaic cell is easily affected by the radiation intensity, environment temperature, and factors like shadows, clouds, etc. In this paper, the photovoltaic cell output only considers the effects of irradiation intensity and ambient temperature as shown by Equation 2;

$$P_V = P_{STC} G_C [1 + k(T_C - T_{STC})] / G_{STC} \qquad (2)$$

Where G_C stands for the light intensity of work points $G_{STC} = 1kW/m^2$; P_V stands for photovoltaic output power, P_{STC} stands for photovoltaic power rated power, T_C stands for the battery surface temperature $T_{STC} = 25°C$; k stands for the temperature coefficient of the power.

2.3 Storage battery model

The excessive energy from renewable resources is stored in the battery and when there is inadequate energy generated by the renewable resources battery discharges and provides continuous energy. Battery plays a very important role in islanded mode of operations. According to the energy conservation law, storage batteries charge and discharge cycles satisfy the following Equations.

$$\begin{aligned} E_{BAT}(t) &= E_{BAT}(t-1)(1-\sigma) + P_{BAT\_C}(t)\eta_c \\ E_{BAT}(t) &= E_{BAT}(t-1)(1-\sigma) + P_{BAT\_D}(t)\eta_d \end{aligned} \qquad (3)$$

Where $P_{BAT\_C}(t)$ $P_{BAT\_D}(t)$ is the period t to the outside of the battery charge and discharge system power, η_c η_d is the charge and discharge efficiency of the battery, σ is storage battery drain rate (% / h).

2.4 Diesel generator model

The period t in diesel generator for fuel consumption is given by following Equation 4.

$$V_{fuel}(t) = \xi_{fuel} P_{engine}(t) \quad (4)$$

Where $V_{fuel}(t)$ diesel generator fuel consumption period t; $P_{engine}(t)$ is the diesel generator output power period t, ξ_{fuel} is diesel fuel factor L/kWh.

2.5 Induction motor load model

The power system integrated load model is comprised of induction motor in conjunction with the static load that can be representation of actual dynamic load [19]. This paper considers slip index of the induction motor for TVSMI. The value of slip index is based on either the clearing time of small disturbance or by the reactive power support by the available EVs. It is a measure of voltage induced by the stator to the rotor of induction motor during the fault/disturbance. The slip s of an induction motor is the difference between the synchronous speed and the rotor speed, expressed as a per-unit of synchronous speed [20] and the slip-torque characteristics are given in [21].

2.5.1 Impact of induction motor on transient voltage stability margin in distribution network

Short term interference in voltage mainly refers to dynamic load stability analysis. Dynamic load especially induction motor load has the greatest impact on the transient voltage stability. In extreme conditions it may cause a larger voltage collapse. We consider the dynamic role of induction motor load in perspective of transient voltage stability. It is necessary to study the transient behaviour of the turbulent induction motor connected to the power grid in order to determine the power grid transient stability. The TVSMI can be explained as follows;

1). The slip s can be characterized as a measure of TVSMI [20].

$$s = n_s - n / n_s \quad (5)$$

Where s is the slip, n_s is the synchronous speed (r/min) and n is the rotor speed (r/min). The slip is practically zero at no load and is equal to 1 when the rotor is locked.

2). If S_{scm} represents non-steady state slip (at minimum voltage) and S_{max} the maximum value of induction motor slip (at clearing time), then the TVSMI can be represented as following in Equation 6.

$$\eta = \frac{s_{scm} - s_{max}}{s_{scm}} \quad (6)$$

2.6 EV charging

Different kind of batteries can be employed with the EVs such that lead acid, nickel cadmium and lithium ion etc. The lithium ion batteries are preferred due their higher energy density and their capability of less self- discharging [22]. Moreover different types of chargers can be employed such as high frequency switching (HFS) chargers and phase control (PC) chargers. HFS is preferred for charging at power factor above 0.9; lower harmonic pollution, higher efficiency and fast dynamic response as compared to PC. EV charging has three modes, modes of slow (L1), routine (L2), and fast (L3) charging. These modes have five parts as shown in Table 2.

Table 2: EV charging modes

Charging Modes		Nominal Voltage (V)	Nominal Current (A)	Nominal Active Power (KW)
L1		Single-phase 220	16	3.5
L2	2-1	Three-phase 220	32	7.0
	2-2	Three-phase 380	32	12.1
	2-3	Three-phase 380	63	23.9
L3		600	300	180

Development of charging stations is one of the necessary conditions to increase the penetration of EVs. The EV charging may be divided into three categories containing charging pile, charging station and switch power plant as shown in Table 3.

Although charging piles belongs to the residential users but considering the popularity of the EVs the impact of charging pile cannot be ignored for the transient stability of the distribution network. The operation of charging pile is different from the other household electrical appliances due to the load aggregation. The penetration of EVs can be defined by the following relation given in Equation 7.

$$\rho = \frac{P_{ev}}{P_L} \quad (7)$$

Where ρ is the EV penetration rate, P_{ev} is active power demand for the EVs and P_L is the active power demand for all other load including the induction motor load. The reactive power demand of the EV follows the relation given below;

$$Q_{ev} = \frac{P_{ev}}{PF}\sin(\cos^{-1}(PF)) \tag{8}$$

Where Q_{ev} is the reactive power available by the EV and PF is the power factor of the EV charger.

Table 3: Types of EV charging station

Type of Charger	Charging Time	Suitability
Charging Pile	1-6 Hours	Suitable for Residential Parking at Small Scale in Distributed Fashion
Charging Station	30 Minutes (Approx.)	Suitable for Traffic Intensive Areas/ Highways at Large Scale in Centralized Manner
Switch Power Plant	5-10 Minutes (Approx.)	Suitable for City Centres/ Highways at Large Scale in Centralized Manner

2.7 Transient voltage stability and research response

In recent years, the induction motor, power electronics and other dynamic load has impact on transient voltage stability of the power distribution network and in future more and more electrical vehicles will be in use and it is expected to build large scale EVs charging stations and they will rely on the power electronics controlled devices connected to the power grid and will be in the grid for providing the base load and reduce the stability of the power system. Contrary to fact, with the use bidirectional battery chargers the EVs can be used in V2G mode as spinning reserve and enhance the stability of the grid. As a matter of fact, if the EVs are considered as load as shown in [23], smaller size EVs are considered as threat to the safety of voltage stability of distribution network. To mitigate the peak power drawn by EVs we established a load synchronization algorithm. The purpose of the algorithm is to transfer the extra resource on resource constrained loads in the microgrid and limiting the peak power drawn by EVs using energy management system. The load synchronization algorithm is explained in the next section.

3 Load synchronization algorithm for energy management of EV

Considering the network architecture shown in Figure 1 we balance between the shiftable (EV) and non shiftable loads (other loads) by transferring the extra electrical resource to the resource constrained loads using game theoratic approach. In which each electrical laod plays a non-cooperative game to reach desired optimal point called Nash Equilibrium.

We consider N loads '$i = (1, 2, 3 \ldots.N)$', and time of twenty-four hours '$j = (0, 1, 2, 3 \ldots.24)$' to play a non-corporative game for balancing of loads each hour. First we determine total available resource R_j and fix reference resource RR^i_j for each load 'i' at time 'j' based on history data, to give an estimate to energy supply and management system of usual hourly requirement of each load. Second we consider an important parameter resource share ratio RS^i_j, which is related to predefined percentage of share in R_j. The ESMS allocates the resource RA^i_j for every load based on historic resource share ratio RS^i_j each hour after calculating Rj. Where resource allocation is given by;

$$RA^i_j = R_j \frac{RS^i_j}{\sum_{i=1}^{N} RS^i_j} \tag{9}$$

After resource allocation we determine surplus or deficiency SD_{ij} of resource to the load using Equation 10. Load having more RA^i_j reference resource RR^i_j has surplus resource (SD^i_j >=0), otherwise deficiency of resource.

$$SD^i_j = RA^i_j - RR^i_j \tag{10}$$

Before re-distribution of resource we add all the surplus resource to get total surplus sum TSS_j for any stage of time 'j' and in a similar manner add deficiency of resource to get total deficiency sum

TDS_j. Where, TSS_j is available for auction. We consider that non-shiftable loads have strict resource requirements and shiftable loads have minimum resource requirements. It is important to satisfy non-shiftable loads before re-distribution whereas if the resource cannot fulfill the minimum requirement of shiftable loads, they can be preempted to switch-off. Resource re-distribution RD_j is calculated after satisfying the non-shiftable loads and iteratively distributes extra resource to resource deficient loads one unit a time, which is given by Equation 11.

$$RD_j = \frac{TSS_j}{TDS_j} \tag{11}$$

Next we calculate surplus/deficiency reserve after re-distribution $SRAR^i_j$ or $DRAR^i_j$ for loads 'i' at time of equilibrium 'T_j' as given in Equation12 and Equation 13.

$$SRAR^i_j = RA^i_j - RD_j \tag{12}$$

$$DRAR^i_j = RA^i_j + RD_j \tag{13}$$

Surplus resource will be distributed it to the high priority devices PR^i_j. Like if the requirement of setpoint operated devices is not fulfilled they will be considered now, moreover if the resource cannot fulfill the minimum requirement of shiftable loads, they can be preempted to switch-off. Now we calculate the satisfaction level SL^i_j of each load by Equation 14;

$$SL^i_j = \sum_{i=1}^{N} PR^i_j \frac{SRAR^i_j}{RR^i_j} \tag{14}$$

Based on resource re-distribution, satisfaction level is calculated after complete resource re-distribution. It defines how much resource a load has received as compared to its reference resource. Strategy that maximizes the satisfaction and payoff for each player is the equilibrium strategy for this stage. It is termed as Nash Equilibrium in game theory. The equilibrium or optimal point is calculated by;

$$EQ^i_j = \arg_{T_i \in X_j} \max SL^i_j \tag{15}$$

Equation 15, calculates the expected optimal point after resource distribution and try to give the best response by all players in current stage of the game because at this time no player has benefit to deviate from this point. The idea is not to find a global optimal but rather a local optimal solution.

4 Co-Simulation Platform for Energy Management System

There are many real time simulators such as RTDS, HYPERSIM and ARENE [11-14]. These simulators have the capability to test the power network in real time like QualNet [10]. Real time simulator has the capability to run complex models at the same time as the physical time. There are tremendous advantages of using real time simulators in terms of development time and lesser costs once they are integrated with the HIL and SITL models. For example it will advantageous to use HIL simulations under altered conditions and situations, such as for normal and transient situations otherwise it would be expensive or challenging to investigate with a physical plant. Real time simulation is not the goal of our research however the focus is to incorporate the power system network and communication network seamlessly.

It is assumed that all subsystems are coordinated together with very high accuracy permitting several controls under test to be coupled to the system instantaneously. There are four main objectives for modelling and simulation of energy management system;

- Design of control algorithms for energy supply and management system.
- Deduce the communication requirements on the performance of control algorithms.
- Better design of the controller.
- Development of flexible and modular simulation environment.

These requirements are important for investigating in the context of energy management system for the development of smart charging algorithms that can reduce peak power; minimize the energy costs and optimal use of renewable energy sources.

4.1.1 Communication effects in control system

EVs may be considered as dynamic load needing great amount of power from the network but also can supply power in V2G mode. Appropriately planned and organized network can deliver ancillary services for example, frequency regulation by adjusting the active power flow and the reactive power support through supply and demand matching.

Communication thus plays an important part in handling the supply of energy. It is important for the charging station about the status of the grid in order to well assessment of time for charging [24]. Different communication methods can be adopted for charging stations such as IEEE 802.15.4 (Zigbee), Power Line Carriers (PLC) etc. [25].

Integration of power, control and communication network reflected as Networked Control System (NCS) in which there is a communication between the distant controller and plant. It is important to mention here that there are numerous communication aspects which upset the performance of NCS like, packet losses, packet size, packet disordering and the bandwidth. Hence, ideally NCS can be considered as stable while unstable in physical conditions.

4.1.2 Nature of delays

In [26] it is shown that delay can be disintegrated into two portions sensor to actuator τ_{sc} and controller to actuator τ_{ca} as shown in Figure 3: In order to model the system correctly it is important to classify the nature of delays like, arbitrary, constant or time varying, and constrained or non-constrained, subject to Medium Access Control (MAC) protocol [27].

There are varieties of medium access protocol for wired and wireless networks including Token Bus, Token Ring, Token Passing, Time Division Multiple Access (TDMA), and Carrier Sense Multiple Access (CSMA). Where, a CSMA protocol offers uncertain or random delays e.g. Ethernet and Controller Area Network (CAN) while TDMA or Token type's offers deterministic type of latency.

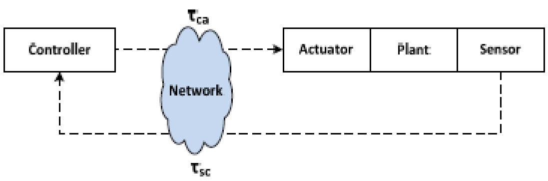

Figure 3: Networked controlled system

4.1.3 NCS modelling

There are different types of control methods for modelling NCS, in which some methods require history of the delays. Stochastic methods are employed for random type of latency like Poisson and Markov [28]. [29] has adopted discrete approach for the deterministic delays in the NCS:

$$x\left[(k+1)h\right]=\phi x[kh]+\Gamma_0(\tau_k)u[kh]+\Gamma_1(\tau_k)u\left[(k-1)h\right] \quad (16)$$

Where, h is the sample period and

$$\tau_k=\tau_{ca}+\tau_{sc}$$

$$\phi=e^{Ah}$$

$$\Gamma_0=\int_0^{h-\tau_k} e^{As}Bds$$

$$\Gamma_1=\int_{h-\tau_k}^{h} e^{As}Bds$$

Furthermore the system can be represented in the form;

$$\bar{x}[k+1]=\bar{A}\bar{x}[k]+\bar{B}\bar{u}[k] \quad (17)$$

Where,

$$\bar{A}=\begin{bmatrix}\phi & \Gamma_1\\ 0 & 0\end{bmatrix},\ \bar{B}=\begin{bmatrix}\Gamma_0\\ 1\end{bmatrix},\ \bar{x}[k]=\begin{bmatrix}x[k]\\ u[k-1]\end{bmatrix}$$

If the periodic delay is less than the sample time, the system will be considered time invariant and proceeding relation will give the stability of the controller; ; $u[k]=-Kx[k]$, by calculating the eigenvalues of the matrix $\left(\bar{A}-\bar{B}[K \quad 0]\right)$ [30].

This method will be adopted for the development of smart grid. It is possible to simulate the above simulation given in section 2 using the above communication model.

5 Case study

In this section, a case study of a modern distributed system is presented. The purpose is to verify the effects of bi-directional power flow on the power quality of the distribution network. There are increased fault current due to the distributed generations, malfunctioning of protection system and phase imbalance.

EVs are considered as active loads. They may affect the transient voltage stability of the distributed network both in charging and discharging (regeneration) mode of operation. The effect is likely to be substantial due the increasing penetration of EV and increase in use of induction motor load. The resultant effects are analysed for the design of better EV interface devices and future power networks.

It is possible to design the EV interface to eliminate the effects of EV on the network fault level and the protection system. However, their effects on the network such as loading, voltage profile, and phase imbalance and power quality could be significant and need to be properly addressed.

5.1 Model Description

Consider radial network shown in Figure 1. Each feeder contains different portions of static load in parallel to the induction motor load such as, Feeder A contains residential subscriber loads containing ordinary loads (about 50% induction motor load), static loads and charging pile for charging of EVs. while feeder B, feeder C, and feeder D are commercial building subscriber loads which contain less-sensitive loads (about 65% induction motor load) and static load, ordinary loads (about 50% induction motor load) and static loads, and sensitive loads (about 75% induction motor load) and static loads, respectively. The charging station deployed at feeder D is considered to provide transient voltage stability for this research. The battery SOC can be reached by 80%-90% within 30 minutes. EVs are normally in constant current charging and its active power is far more than the constant voltage charging. For this research the charge current and discharge current is of worth importance. As given in Table 2 the routine charging for our case has DC bus voltage of 380V, the charging current is 63A, and the active power is 24kW.

The distribution network has two modes of operation grid connected and islanded. During grid connected mode the battery storage inverter is delegated to retain constant dc voltage and in order to have constant current level in charging and discharging mode, dc-dc converter is delegated to operate in constant current controller mode. In islanding mode the battery inverter will provide constant grid voltage and the dc-dc

When there is three phase fault happens at the grid, a signal is sent to the microgrid ESMS to synchronize the load. If there is voltage instability indicated by any bus the charging station is requested for the reactive power support. The measurements sent through the communication link contain packet losses, latency and bandwidth limitation as discussed. As the EVs penetration increases to the system or by the increase in motor load a fall on the ac bus voltage indicates that static as well as dynamic load has to be served.

In our simulation first we considered the impact of increasing EV load (charging mode of EVs). Later we considered the impact of increasing penetration of EV (discharging mode of EVs) in order to conform the TVSMI explained in section 2.5.1.

5.2 Model distribution

The distributed network model is mainly distributed into power system and communication system interfaces. DIgSILENT Powerfactory and OPNET can be used for the simulation of continuous time and discrete event system simulations.

5.3 Simulation Analysis and Results

Considering that the demand of charging the EV reaches maximum and the Feeder D has bigger proportion of induction motor, it is expected that this feeder can lose the stability within no time on a 3 phase fault at the power grid. It is noteworthy that increasing load of EV as it reaches about 40% the system will become unstable i.e. with the increasing penetration of EV load the transient voltage stability margin becomes lower due to decrease in the node voltage as shown by Figure 4.

The charging station merely supports completely in this situation and the system will be going to be unstable in this situation. In order to improve the TVSMI the EVs penetration may be increased in V2G mode. By increasing the penetration in V2G mode the transient voltage margin index follows the EV discharging in an event of fault and the state of distribution network will transfer from and unstable state to the stable state. The impact of EV penetration to maintain the voltage stability of the node is shown in Figure 5.

Hence, it is proposed that configuration of EVs has to be changed from charging mode to discharging (V2G) mode. The critical clearing time as depicted by the TVSMI is very much important and reconfiguration of EVs must fast enough to maintain the TVSMI.

In our study we considered separate transient voltage stability margin indices for static load, complex loads and the EV loads and found that with the increasing EV load the TVSMI become lower, there is an indirect relationship between increase in EV load and the TVSMI. Moreover there is direct relationship between EV penetration and the TVSMI.

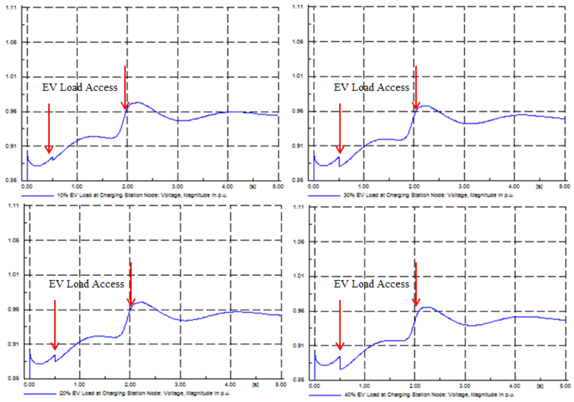

Figure 4: Impact of EV load on voltage stability

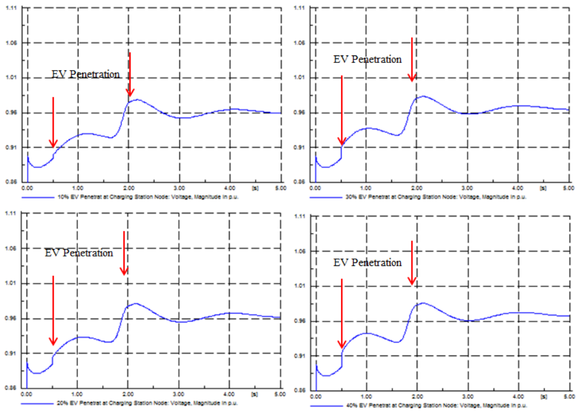

Figure 5: Impact of EV penetration on voltage stability

6 Conclusions and future works

This paper discusses about the impact of energy management of EVs on transient voltage stability of microgrid. In the presence of fault of in the power grid, the microgrid is islanded. Energy management is necessary to balance the demand and supply. EVs can provide the base load for short term and can act as spinning reserve to enhance the grid stability. Transient voltage stability of the distribution network especially microgrid can be achieved through the penetration of EVs. Furthermore, the use of induction motor load is also increasing and induction motor is a threat for grid stability either during start-up/ disturbance. We are keen to normalize the transient behaviour of induction motor load through the EVs. In this paper we have proposed a TVSMI as measure of stability of the distribution network/microgrid. Moreover we proposed an energy management algorithm for the distributed vehicles in the microgrid for the purpose of load synchronization. The energy management algorithm and TVSMI may be used in conjunction to limit the number vehicles in the network and managing configuration of the vehicles either as load or source. In order to fully exploit the idea the co-simulation of the energy management system may be implemented in future.

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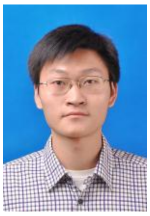

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