Investigating Smart Grid Approaches for optimal Integration of PV Distributed Energy Resources in Dubai

Moustafa A. M. Shahin[1], Evangelia Topriska[1], Michael Gormley[2]

[1] EGIS, Heriot Watt University, Dubai, UAE
[2] EGIS, Heriot Watt University, Edinburgh, UK

Abstract

The rapid deployment of grid-connected roof-top photovoltaic systems in Dubai, as part of "Shams Dubai" initiatives and the anticipated high penetration of distributed PV generation have both raised several challenges and urged the need to study the technical solutions to address higher PV penetration levels. The intermittent nature of PV distributed generation could adversely impact the voltage profile and stability of distribution feeders throughout the daily load cycle resulting in voltage fluctuations and flicker that violate the established utility guidelines for voltage regulations. Moreover, the existing distribution networks were not designed to operate with intermittent sources of generation at medium or low voltage levels.

This paper discusses several smart grid strategies for Distributed Energy Resources (DER) integration including advanced control of smart inverters, automated demand response, and technical and regulation enhancement for DER integration to improve the PV hosting capacity of distribution feeders and enable wider deployments of roof-top PV systems, thus achieving successful renewable transformation of the existing power systems. A survey was conducted to investigate the existing solar PV projects in Dubai and identify the key challenges of the existing interconnection standards. The initial survey results and recommendations for PV integration strategy and grid interconnection regulations enhancement are presented.

Keywords: Grid-connected PV integration, DER integration, smart grid strategy, Shams Dubai, advance inverter management, DER interconnection regulations.

1. Introduction

In the UAE, the use of clean energy sources and low-carbon electrification are receiving increasing attention with the clean energy target set to increase to 24% by 2021 compared to about 1% toady. As part of the UAE‘s commitment to the Paris Climate Agreement, the clean energy strategy 2050 emphasised on diversifying the energy mix with more focus on clean energy shares. 25% of Dubai’s total energy by 2030 and 75% by 2050 is predicted to come from renewable energy sources in order to transform Dubai into a global centre of clean energy with the smallest carbon footprint in the world (Dubai Carbon, 2017).

Shams Dubai programme was launched in 2015 to encourage household and building owners to install PV panels to generate electricity to feed their own loads and export the surplus to the utility grid. In two years, Four hundred and thirty five buildings have already installed photovoltaic panels on their roofs and generated a total capacity of 15.6 Megawatts (Gulf News, 2017).

The existing energy policy and grid standard of renewable distributed energy resources (DER) interconnection in Shams Dubai regulations imposed some restrictions to limit the capacity of distributed PV connections compared to the total connected loads of the customer in order to avoid the well-known concerns of integrating high PV penetration into distribution feeders (DWEA Shams Dubai, 2015 & 2016). However, those restrictions could limit larger PV deployments and hinder the achievement of the strategic targets of Shams Dubai initiatives to increase Dubai’s share from clean energy sources to 75% by 2050. Smart grid technologies provide a more viable solution to address DER integration challenges at high PV penetration levels without limiting PV grid-connected capacity.

doi:10.18086/swc.2017.01.02 Available at http://proceedings.ises.org

2. Integration Strategies for PV distributed generation

Electric utilities around the world are seeking to develop strategies to increase resilient integration of DER integration while maintaining the grid performance. The IRENA study on PV integration emphasised on the importance on developing integrated strategy that covers technical, regulatory and economic aspects in order to tackle PV integration challenges successfully. The common theme of all implemented measures was to introduce additional flexibility into the existing power systems to accomdate renwable distibution genersation at different voltage levels (IRENA, 2017).

A study by the IEA's photovoltaic power systems programme on urban photovoltaic electricity policies concluded that GC-PV can be the solution to growing demand in the dense urban environment. In the perspective of a large photovoltaic deployment, it is quite important to have upfront good integration policies to assure that GC-PV is deployed with the maximum benefit to the community while reducing actual installation barriers associated with grid codes and permits. (IEA PVPS, 2009 & 2016). Sweco et al. investigated DER integration strategy in order to provide flexibility to the distribution power system and highlighted that the technologies needed for DER integration are available; the key challenge is to adjust to the regulatory framework and DER interconnection policy to make the market ready (Sweco et al., 2015). A survey was conducted by the authoers to investigate the strategies that provide flexibility measures for DER integration in which smart grid experts were asked about the following smart grid stregies as shown in Figure 1.

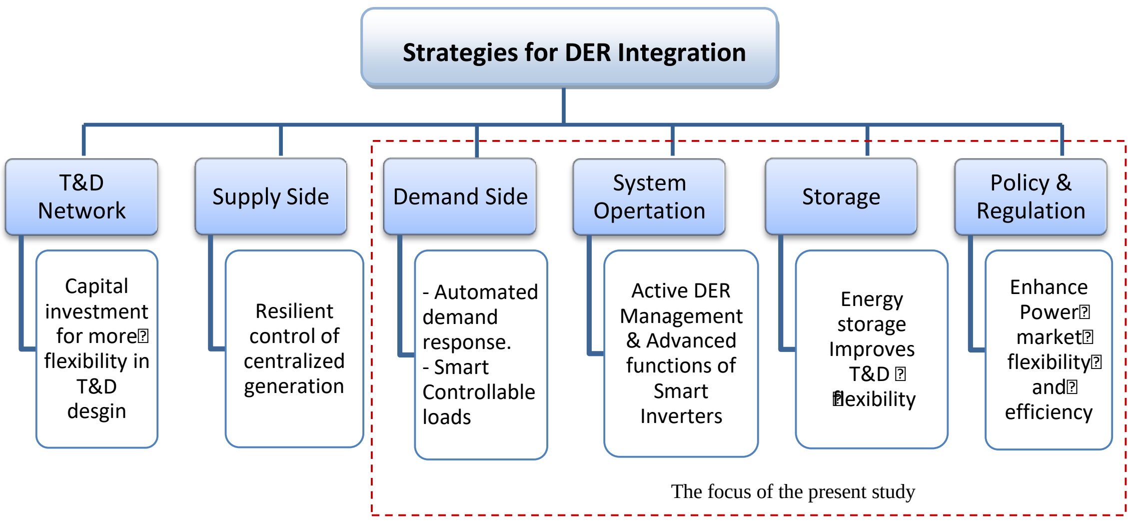

Figure 1: Smart Grid Strategies to improve the flexibility of the grid systems and DER Integration

Supply side and T&D networks integration strategies often require large capital investments are not considered for low and meduim DER penetration levels. This paper focuses on DER integration strategy based on advanced control of smart inverters, and policy/regulations enhacement to cope with the technology advancement. The majority of respondents (72%) viewed that advanced inverter functions offer a cost-effective solution to address the challenges of DER integration. Fifty eight perecent (58%) of the respondents considered that energy storage are not currently economical for grid-connected PV systems specially in Dubai and the gulf region.

2.1 PV Hosting Capacity of Distribution Feeders:

The concept of PV hosting capacity is well established in the literature and can be defined as the maximum limit on the amount of photovoltaic generation that can be integrated into a distribution feeder with no violation of grid operational conditions. (Whitaker et al. 2008; Reno et al. 2013; Dubey, Santoso, and Maitra 2015 ; Obi & Bass 2016; Palmintier et al. 2016a; Pecenak, Kleissl and Disfani, 2017)

The term photovoltaic penetration (PV_{pen}) could be defined as the ratio of the installed PV power to the peak load of a feeder (Pecenak, Kleissl and Disfani, 2017). Instantaneous PV_{pen} at a given time (t) can be obtained as:

$$PV_{pen}(t) = \frac{PV_{ins}\,(t)}{Load\,(t)} \text{(Eq 1)}$$

Where P_V is the photovoltaic installed power. Percentage penetration level % PV_{pen} for a given feeder configuration can be approximated as given in Eq2 below.

$$\%PV_{pen} = \frac{P_{V\,(Peak)}}{Load_{(peak)}} \text{ x } 100 \text{(Eq 2)}$$

Many simulation studies and demonstration projects concluded that the integration strategy of PV distributed generation is dependent on the PV penetration level and location of PV system. EPRI research projects for several GC-PV case studies prove that PV penetration levels below 15% did not demonstrate integration issue. The voltage regulation issues due to distributed PV generation and the impact of PV location on the voltage profile of distribution feeders are illustrated in Figure 2 below.

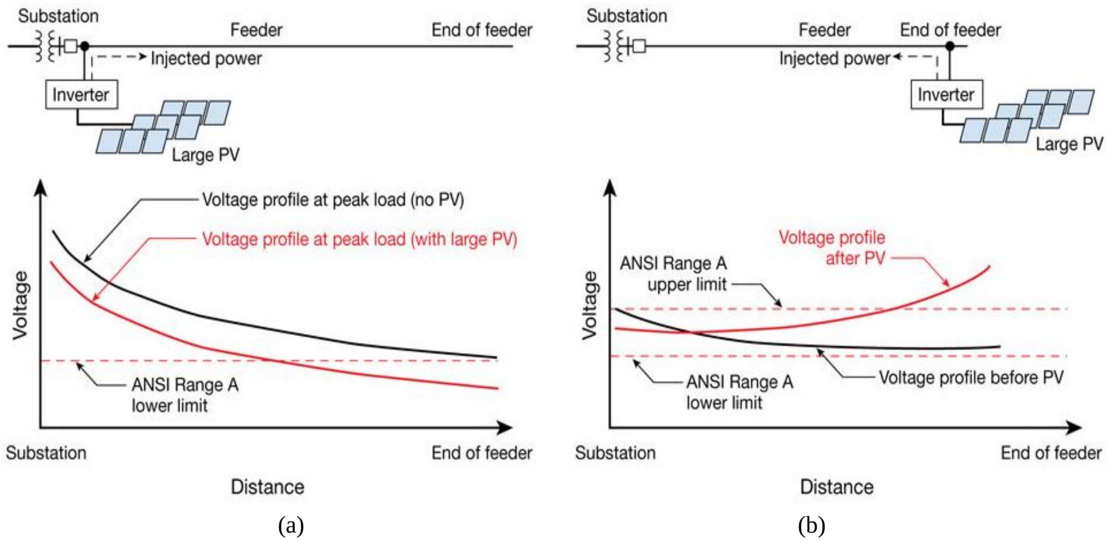

Figure 2 Voltage profile due to distributed PV generation. Figure 2.4a for GC-PV system at feeder's head while figure 2.4b shows CG-PV system at the end of the feeder (EPRI, 2013).

The analysis of many simulation studies of PV penetration on distribution feeders with EPRI's PV hosting capacity model concluded strong correlation with voltage regulators and feeder characteristics. Other significant factors include the location of point of connection (POC) of PV generators. On the other hand, EPRI's analysis concluded no significant correlation between hosting capacity and the peak load of the distribution feeder (EPRI, 2013). Figure 3 shows the hosting capacity in terms of voltage violations with the increasing penetration level of grid connected photovoltaic (GC-PV).

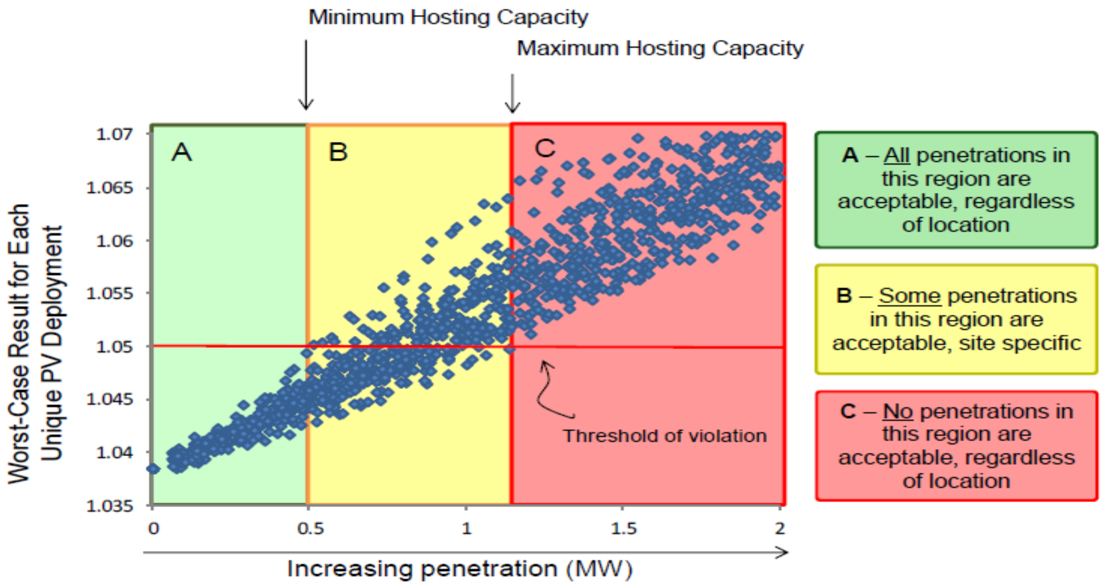

Figure 3: The voltage limit violation with the increasing penetration of GC-PV (EPRI, 2013)

The feeder's voltage profile issue due to PV DER integration can be explained in the view of the highly simplistic two bus feeder model shown in Figure 4. The voltage at substation bus is assumed to be constant as the nominal voltage with a magnitude of 1 per unit (p.u).

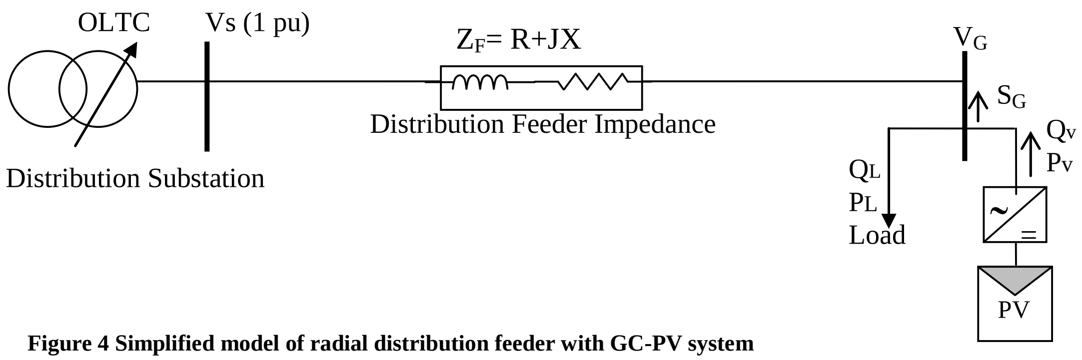

Figure 4 Simplified model of radial distribution feeder with GC-PV system

The voltage difference between substation bus (S) and distributed generation bus (G) is defined as:

$\Delta V = Vs - V_G = I \text{ x } Z_F = .(R+jX)$ (Eq. 3)

Where I is the current flowing from the DG-PV source (I) Ignoring the wiring power losses can be found using:

$I = \frac{S_G}{V_G}$ (Eq. 4)

The total apparent power S_G injected to the grid at the DER bus S_G can be calculated in terms of active power (P) and reactive power (Q) as:

$$S_G = (Pv - P_L) + j(Qv - Q_L) = P + jQ \qquad \text{(Eq. 5)}$$

And the absolute value is $|S_G| = \sqrt{P^2 + Q^2}$ (Eq. 6)

Where Pv and Qv represent the active and reactive powers generated by the PV inverter respectively; and P_L and Q_L represent the active and reactive power consumed by the load respectively.

The power factor (PF) by definition is the ratio of the real power to the apparent power in the circuit:

$$\text{PF}=\frac{P}{S_G}=\frac{P}{\sqrt{P^2+Q^2}}\cong\frac{\text{I}^2\,\text{R}}{\text{I}^2\sqrt{R^2+X^2}}\cong\frac{\text{R}}{\sqrt{R^2+X^2}} \qquad \text{(Eq. 7)}$$

The current (I) flowing from the GC-PV to the DER bus. Ignoring the wiring loss through the can be found using:

$$\text{I}=\frac{P+jQ}{V_G} \qquad \text{(Eq. 8)}$$

Combining (2. 3) and (2.8), hence: $\Delta\text{V}\cong\frac{\text{P.R+QX}}{V_n}$ (Eq. 9)

The overvoltage caused due to distributed generation depends on the variables in equation (9). V_n is the nominal grid voltage as set by the distribution utility and could not be controlled. Different methods have been developed to increase the PV hosting capacity focus on controlling one or more variables of the equation 2.9 numerator. For instance, Inverter volt/var controls reactive & power power (P, Q); while feeder reinforcement aims to control X/R values.

2.2 *Advanced Inverter Functions for improving PV hosting capacity:*

Current grid-connected PV systems use advanced inverters that become smart enough to operate autonomously according to pre-established software settings and with the addition of communications capabilities, DER systems can be directly monitored and controlled by utilities to modify or override their autonomous operations. DER systems can receive remote emergency commands, demand response pricing signals or schedules of modes/ commands to cause the inverters to change their electrical characteristics such as voltage levels, energy production rate, and active or reactive power outputs according to daily, weekly, or seasonal timeframes so long as they operate within the standard requirements of the interconnection regulations of the grid (see Table1) .

Smith et al. investigated inverter volt/var control through simulation study and concluded that the effectiveness of inverter based control for PV integration into the distribution system. Similarly, several simulation studies concluded that volt/var management is an effective strategy for distribution voltage regulations however, feeder characteristics shall be taken in conciderations (smith et al. 2011; Rizy et al 2011; Schauder and Mather 2014; Kim et al., 2016; Leite et al 2016).Alobeidli and Moursi compared different coordinated volt/var control strategies using conventional methods like OLTC and inverter-based control. They reported that inverter-based strategy is proven to be an efficient strategy for DER integration to improve feeder voltage profile and maximize reactive power reserve up to 80% (Alobeidli & Moursi, 2014).Rylander et al. and others analysed the potential performance benefits of advanced inverter control on different distribution feeders. The advanced volt/var function of the inverters improved PV hosting capacity between 43% and 133% (Rylander et al. 2016; Seuss et al. 2015)

Table 1: Advanced inverter functions to support DER integration (EPRI 2012; Rylander et al. 2016; Casey et al. 2010; Bower et al. 2012)

Classification	**Inverter Functions**	**Associated Standards**
Autonomous Functions: • *Behavior controlled by inverter's pre-configured operating parameters (defined during system commissioning).* • *Parameters can be re-configured, activated or deactivated at later date through on-site changes or remotely.* • *No communication capability is required.*	Low- / High-voltage ride-through	IEEE 1547a-2014
	Low- / High-frequency ride-through	
	Volt-var control (dynamic reactive power injection)	
	soft-reconnect	
	Ramp-rate controls	
	Fixed power factor	
Non-Autonomous Functions:	Remote connect/disconnect command to DER	

• *Direct control of inverter behavior from remote operator commands or feedback, based on conditions at the point of connection (POC)* • *Communication architecture and remote control infrastructure are required.*	system	IEEE smart inverter working group (SIWG) proposed Functionalities
	Set /Limit real power	
	Respond to real power pricing signals	
	Update/overwrite autonomous functions (volt-var curves, fixed power factor, voltage ride-through, frequency ride-through, ramp rate)	
	Provide black-start capability	
	Provide spinning reserves	
	Event/history logging	
	Status reporting	

Palmintier et al. investigated several active and reactive (volt/var) power management strategies of PV integration at different penetration levels. This could be achieved typically through controlling on-load tap changers of transformers, capacitor banks and line regulators. A techno-economic assessment of different volt/var strategies to enhance PV hosting capacity concluded that on-load tap changers of distribution transformer could be effective can prove only when PV penetration level exceeds beyond 75% (Palmintier et al. 2016a). For lower penetration levels (typically between 15% to 75%), PV inverter's reactive power support and active power control have been demonstrated in several studies to mitigate voltage regulation and power quality issues that could occur due to large PV deployment in the distribution grid (Palmintier et al. 2016b ; Wang et al. 2014).

Further, Hashemi, Ostergaard, and Yang suggested that advanced inverter control is a cost-effective solution to control active/ reactive power through the output curtailment functionality of advanced PV inverters and could therefore decrease the required storage capacity for grid balancing (Hashemi, Ostergaard, and Yang 2013)

3. Data Collection

3.1 DER Integration Survey:

A survey was conducted to investigate the existing solar PV projects in Dubai and identify the key challenges of the existing interconnection regulation of distributed energy resources (DER) related to advanced inverter management. The survey was circulated to participants represent Shams Dubai's experts from utility industry, PV inverter manufacturers; enrolled consultants and contractors in Shams Dubai programme as provided on DEWA website (DEWA Shams Dubai, 2017). The initial results of the survey revealed that advance remote management of DER system of smart PV inverter could be achieved through below list of advanced inverter functions ranked based on the feedback of the participants as shown in Figure 5. Remote configuration of inverter's power factor and real time volt/var management of smart inverter are among the most important capabilities to improve PV hosting capacity of distribution feeders.

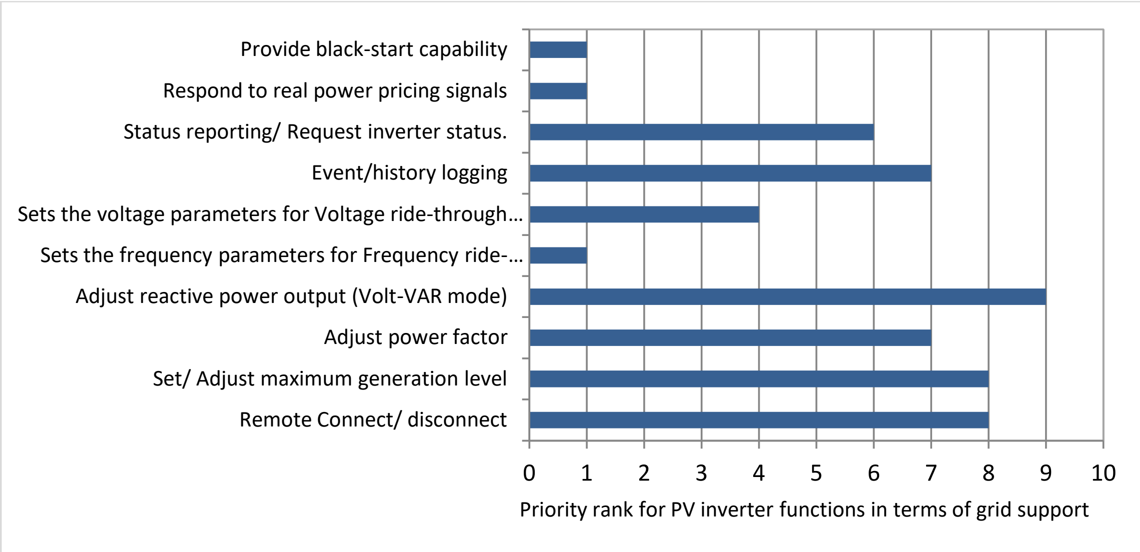

Fig 5: The key inverter's functions that could be remotely controlled/ re-configured for smooth DER integration.

The survey results also revealed that that some integration and interconnection regulation challenges shall be addressed to enable wider deployment of roof-top solar PV as shown in Figure6. The following challenges were identified:

- The interconnection standard is lagging behind the technological advances of smart inverters. The grid codes in Dubai did not cover some inverter's supporting functions like dynamic reactive power support during low voltage ride through (LVRT), hybrid inverter, inverter's volt/var and volt/watt modes.
- PV storage is not covered by the regulations.
- Dubai grid codes imposed restrictions to limit the maximum capacity of PV connections based on total connected Loads.
- Unclear guidelines about technical/ communications Architecture for of PV inverters remote monitoring & control by the utility through IEC61850.
- Lack of compensation mechanisms for DER aggressors (energy retailers) or ancillary service providers. The current grid codes did not support feed-in tariff or compensation scheme for energy service provides.

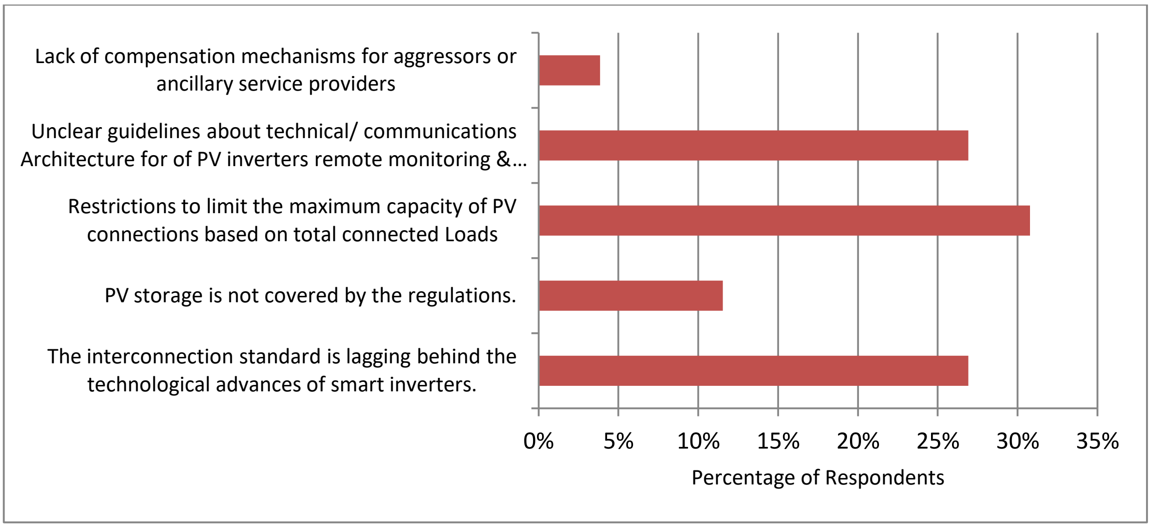

Fig 6: The key challenges you are facing with the existing PV interconnection Regulations and Standards.

3.2 Model Development:

The test system includes PV plant connected to 11KV (9 bus) distribution Feeder, Capacitor bank and OLTC substation transformer (see figure 7) include the flowing sub-systems:

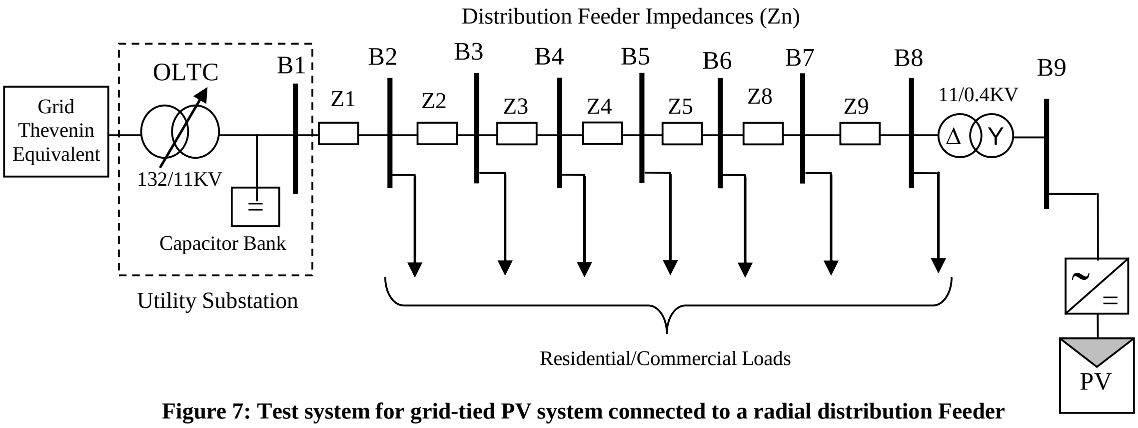

Figure 7: Test system for grid-tied PV system connected to a radial distribution Feeder

In order to examine the impact of inverter's volt/var control and other advance functions for remote monitor/ control, transient analysis for PV power fluctuation during irradiance dip or sundden PV system's failure at different penetration levels. The voltage source converter (VSC) in modern inverters can be controlled using digital signal processing (DSP) and microcontroller to compute the slope (dP/dV or dP/dI) of the PV power curve and feed it back to VSC control to drive it to zero (Sumathi, Ashok, & Surekha, 2015). Block diagram of smart inverter mamangemt through remote terminl unit (RTU) and demand response commands from Distributed Energy Resources management system (DERMS) as shown in figure 8.

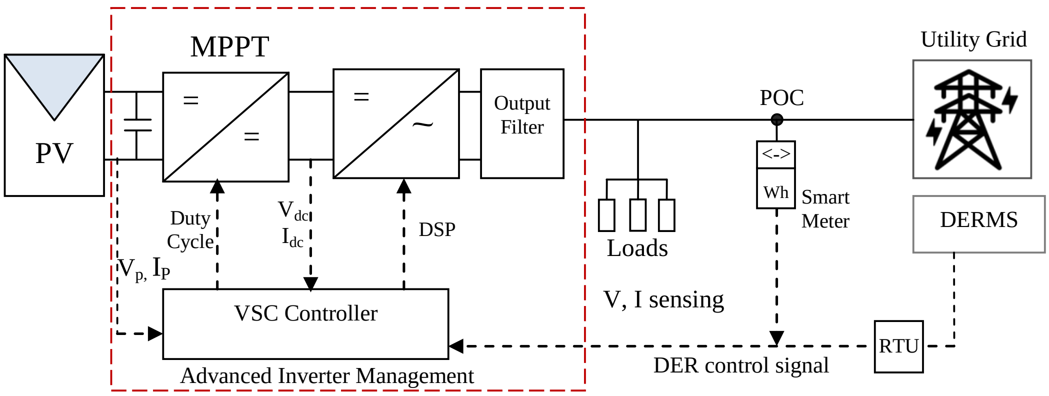

Figure 8 Smart Grid Approach for DER integration through advanced Inverter management and DERMS.

MATLAB/SIMULINK model reflecting grid-tied PV system is developed using Simscape power system components. A screenshot of the preliminary model is given in figure 9. The main components of grid-connected PV system connected to the model are:

(1) PV arrays comprises of SunPower SPR-315E modules. A photovoltaic module is commonly represented by an electrical equivalent one-diode four parameter model (Rekioua & Matagne, 2012). .

(2) DC/DC boost converter connected to each PV array controlled by a Maximum Power Point Tracker (MPPT) using P&O "Perturb and observe" algorithm to control PV array voltage in order reach the maximum power output.

(3) , (4) DC/AC Voltage Source Converter (VSC) control and a coupling 3-ph transformer to connect the converter to the distribution feeder.

(5) , (6) The grid model consists of typical 11kV distribution feeders and 132kV equivalent transmission system (DEWA Design guidelines, 2015).

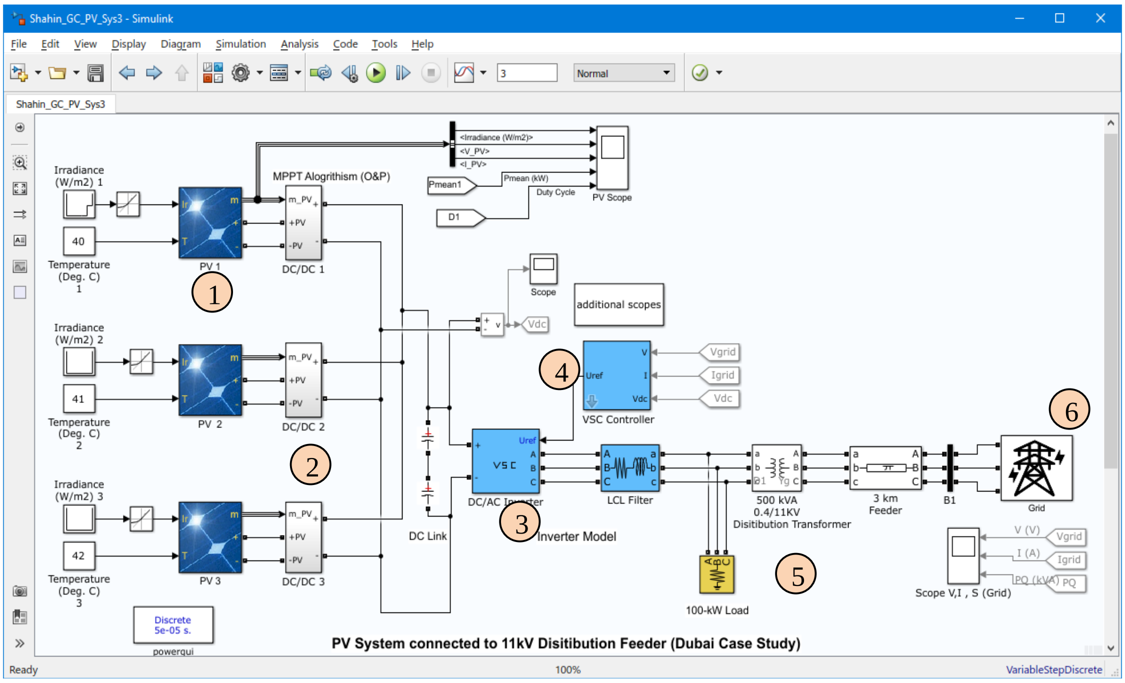

Figure 9: MATLAB/SIMULINK Model for GC-PV system connected to 11KV distribution feeder

4. Conclusion

In conclusion, it has been proven in the literature that advanced smart inverter functions and dynamic volt/var control are cost-effective strategies to improve PV hosting capacity of distribution feeders and help to mitigate adverse voltage impact compared to the conventional voltage regulation methods through OLTC which are more costly and have a slower response compared to smart inverters. However several simulation studies concluded that specific methods based on distribution network design and feeder's characteristics (mainly X/R ratio) should be developed to define the optimal inverter settings and functions for DER integration.Interconnection regulations need to be developed to cope with technolgoy advancesof the modern DER system rather than imposing limitation on the maximum PV power generation and the annual connection capacity to avoid the challenges of intermittent uncontrolled distributed generation. Based on the initial results of DER integrationsurvey, the following are key recommendations for further enhancement of DER interconnection regulations:

- The interconnection standard is lagging behind the technological advances of smart inverters. Advanced solar inverter features like advanced inverter’s volt/var management need to be investigated and supported by the regulations.
- Hybrid inverters with PV storage shall be supported for feed-in tariff.
- Clear guidelines about communications protocols and technical architecture to be developed for utility’s remote management of PV inverters.
- The proposed volt/var control settings (as recommend by IEEE P1547 working group) to be used as default inverter settings with most distribution feeders.
- Multiple volt/var profiles of smart inverters should be scheduled based on seasonal load profile to optimize the voltage profile of distribution feeders.
- Compensation mechanisms for ancillary service include volt/var control through smart inverters.

For future work, the dynamic volt-var control capability will be incorporated into inverter model and applied to an actual distribution feeder model in Dubai to investigate the impact on the chosen performance objective of the distribution network. Other DER management capabilities will be explored, such as scheduling multiple volt/var profiles for a residential PV systems based on seasonal load profiles for typical residential buildings.

5. References

- Alobeidli K., Moursi M.S. (2014) Novel coordinated secondary voltage control strategy for efficient utilisation of distributed generations. IET Renewable Power Generation 2014, Vol8, Issue5, pp. 569-579.

- Bower w., Sigifredo Gonzalez, Abbas Akhil, Scott Kuszmaul, et al. (2012)Solar Energy Grid Integration Systems: Final Report of the Florida Solar Energy Center Team. Sandia National Laboratories SAND2012-1395

- Casey, Leo F. ; Schauder, Colin ; Cleary, James ; Ropp, Michael (2010) Advanced inverters facilitate high penetration of renewable generation on medium voltage feeders - impact and benefits for the utility. IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply, Sept. 2010, pp.86-93

- Denholm, Matthew O'Connell, Gregory Brinkman, and Jennie Jorgenson (2015) Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart. National Renewable Energy Laboratory NREL/TP-6A20-65023 http://www.nrel.gov/docs/fy16osti/65023.pdf.

- DEWA Shams Dubai (2017) List of companies enrolled with DEWA as "Electrical & DRRG Solar PV" Consultant and Contractors for the Shams Dubai program. Available at: https://www.dewa.gov.ae/images/smartinitiatives/Shams_Dubai_Consultants_and_Contractor_list.pdf

- DEWA SHAMS DUBAI 2015. - Connection conditions for generators of electricity from solar energy Version 1.1 . https://www.dewa.gov.ae/images/smartinitiatives/DEWA_DRRG_Connection_conditions.pdf

- DEWA Shams Dubai. 2016. Standard for Distributed Renewable Resources Generation connected to the distribution network Version 2.0 Dubai Electricity & Water Authority. https://www.dewa.gov.ae/images/smartforms/DEWA_Standards_for_Distributed_Renewable_Resources_Generators.pdf

- Dubai Carbon Centre of Excellence. The state of green economy report 2017 [Online]. Available at: http://dcce.ae/state-of-green-economy-report-2017/[Accessed: 23 February 2017].

- EPRI. 2012. "Stochastic Analysis to Determine Feeder Hosting Capacity for Distributed Solar PV." 1026640. California: Electric Power Research Institute (EPRI).

- EPRI. 2013. "Modeling High-Penetration PV for Distribution Interconnection Studies." 3002002271. California: Electric Power Research Institute (EPRI).

- GulfNews (2017) Shams Dubai achieving impressive results with clean energy plan becoming more critical by the year, this initiative is already quite a pace-setter. Published: August 25, 2017 Available at: http://gulfnews.com/opinion/editorials/shams-dubai-achieving-impressive-results-1.2079948

- Hashemi, S., J. Ostergaard, and G. Yang. 2013. "Effect of Reactive Power Management of PV Inverters on Need for Energy Storage." In Photovoltaic Specialists Conference (PVSC), 2013 IEEE 39th, 2304–8. Tampa Bay, FL. doi:10.1109/PVSC.2013.6744938.

- IEA PVPS (2009) Urban Photovoltaic Electricity Policies. Report IEA-PVPS T10-07:2009 http://www.iea-pvps-task10.org/IMG/pdf/rep10_07.pdf

- IEA PVPS (2016) Trends in photovoltaic applications. International Energy Agency Report PVPS T1-30:2016 http://iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_RA2016-web.pdf

- IRENA 2017, REthinking Energy: Accelerating the global energy transformation.. The International Renewable Energy Agency, Abu Dhabi.

- Kim, Ys ; Kim, Gh ; Lee, JD ; Cho, C (2016) New Requirements of the Voltage/VAR Function for Smart Inverter in Distributed Generation Control. Energies, 2016 Nov, Vol.9(11(

- Leite, L. ; Boaventura, W. ; Errico, L. ; Cardoso, E. ; Dutra, R. ; Lopes, B. (2016) Integrated voltage regulation in distribution grids with photovoltaic distribution generation assisted by telecommunication infrastructure. Electric Power Systems Research, July 2016, Vol.136, pp.110-124

- Obi, M., & Bass, R. (2016). Trends and challenges of grid-connected photovoltaic systems – A review. Renewable and Sustainable Energy Reviews, 58, 1082-1094. doi:10.1016/j.rser.2015.12.289

- Palmintier B., Julieta Giraldez, Kenny Gruchalla, Peter Gotseff, Adarsh Nagarajan, Tom Harris, Bruce Bugbee, and Murali Baggu (2016b) Feeder Voltage Regulation with High-Penetration PV Using Advanced Inverters and a Distribution Management System; National Renewable Energy Laboratory. NREL/TP-5D00-65551 http://www.nrel.gov/docs/fy17osti/65551.pdf

- Palmintier B., Robert Broderick, Barry Mather, Michael Coddington, Kyri Baker, Fei Ding, Matthew Reno, Matthew Lave, and Ashwini Bharatkumar. (2016a) On the Path to SunShot: Emerging Issues and Challenges in Integrating Solar with the Distribution System. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-65331. http://www.nrel.gov/docs/fy16osti/65331.pdf

- Rekioua, D., & Matagne, E. (2012). Optimization of photovoltaic power systems: Modelization, simulation and control. London: Springer.

- Reno M. J., R. J. Broderick, and S. Grijalva, "Smart Inverter Capabilities for Mitigating Over-Voltage on Distribution Systems with High Penetrations of PV," in IEEE Photovoltaic Specialists Conference, Tampa, FL, 2013.

- Rizy, D. Tom ; Xu, Yan ; Li, Huijuan ; Li, Fangxing ; Irminger, Phil (2011) Volt/Var control using inverter-based distributed energy resources. IEEE Power and Energy Society General Meeting, July 2011, pp.1-8

- Rylander M. , Matthew J. Reno , Jimmy E. Quiroz , Fei Ding , Huijuan Li , Robert J. Broderick, Barry Mather, and Jeff Smith (2016) Methods to Determine Recommended Feeder-Wide Advanced Inverter Settings for Improving Distribution System Performance. USA. SANDIA http://energy.sandia.gov/wp-content/uploads/dlm_uploads/2016/06/SAND2016-4864C_PVSC-CSI4_MethodsAdvancedInverterSettings.pdf

- Samadi, A., R. Eriksson, L. Söder, B.G. Rawn, and J.C. Boemer. 2014. “Coordinated Active Power-Dependent Voltage Regulation in Distribution Grids with PV Systems.” IEEE Transactions on Power Delivery 29 (3): 1454–64. doi:10.1109/TPWRD.2014.2298614.

- Sandia National Laboratories (2012) Solar Energy Grid Integration Systems, Final Report SAND2012-1395, New Mexico USA.

- Schauder C. and B. Mather (2014) Advanced Inverter Technology for High Penetration Levels of PV Generation in Distribution Systems. National Renewable Energy Laboratory (NREL) technical report NREL/SR-5D00-60737 March 2014.

- Seal et al. (2012) Advanced Power System Management Functions and Information Exchanges for Inverter-based DER Devices, Modelled in IEC 61850-90-7 EPRI.

- Seuss, J. Reno, R. J. Broderick, and S. Grijalv (2015) "Improving Distribution Network PV Hosting Capacity via Smart Inverter Reactive Power Support," in IEEE PES General Meeting, Denver, USA.
- Smith J., B. Seal, W. Sunderman, and R. Dugan, "Simulation of Solar Generation with Advanced Volt-Var Control," in 21st International Conference on Electricity Distribution, CIRED, Frankfurt, Germany, 2011.
- Sweco et al (2015) Study on the Effective Integration of Distributed Energy Resources for Providing Flexibility to the Electricity System.