Impact and Interaction of On Load Tap Changer and Smart PV Inverter

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***Abstract*-With great increasing concern about fossil fuel shortage the incentive motivating to improve alternative energy sources. Between renewable energy sources used, energy through photovoltaic is common. Lately, pv system could be widely used as a viable replacement to traditional sources.Unfortunately, PV systems create several challenges to the operation and voltage control to the utilities, So Voltage regulation is needed. Voltage regulation control methods have been proposed in this study considering the inverter of the pv system and OLTC in ieee 15_bus system to regulate the voltage during the studied period. An14_hour simulation is performed considering PV and load variation. The simulation results reveal that the use of smart PV inverter with OLTC may not be the best way to regulate the voltage and there is a need to make coordination between them.**

***Keywords*-PV system, on load tap changer, smart PV inverter, voltage regulation.**

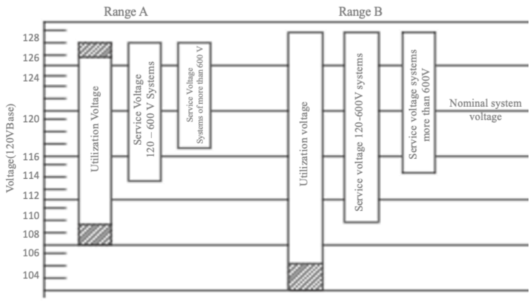
V. INTRODUCTION

The global demand for electrical energy is growing and the interest in renewable energies is also growing internationally. PV is one of the major sources of distributed renewable energy that is predicted to become the biggest contributor to electricity generation. As a result, the level of PV penetration is rapidly increasing specially in distribution networks (low and medium voltage) that may alter the normal operational behavior of distribution networks[1]. Grid connected PV systems could improve grid reliability and solve energy dependence. On the other hand, it leads to many problems for the operation and control of utility grid like reverse power flow, unnecessary operation of traditional voltage regulation device, voltage fluctuation…etc. One of the main problems that mentioned in ieee1547.7(guide aims to describe criteria, scope and extent for engineering studies of the impact on electric power systems of distributed resource interconnected to electric power systems) voltage at PCC and its regulation [2]. Number of solutions like reactive power compensation, storage based solutions and on load tap changer based solutions are developed to mitigate the over voltage problem[3].traditionally, capacitor bank were used to control reactive power consumption of the grid, but the problem is that the capacitors do not have fast switching ability to follow variability of reactive power. Advanced inverter solve this issue with flexible inject or absorb reactive power[4].This paper investigates the interaction between PV inverter and on load tap changer. The study was conducted on ieee_15 bus system with grid connected pv plant (250 kw). The system were modeled on matlab_simulink. The study focuses on how pv inverter and OLTC interacted with each other. As mentioned before, the PV inverter was allowed to supply reactive power and regulate voltage according to ieee1547.7 standard. The PV inverter was controlled to inject or absorb reactive power based on different currently methods to maintain the voltage at PCC within ANSI_limit.

VI. Standard for voltage regulation limits-

As required by the standards, utilities are responsible to maintain the service voltage within acceptable band at the point of the of common coupling. ANSI C84.1 is the American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hz). ANSI C84.1 specifies the steady-state voltage tolerances for an electrical power system. The standard divides voltages into two ranges. Range A and range B, Range A represent the optimal voltage range while Range B represent the acceptable voltage range. Figure (1) shows the ANSI

C84.1 voltage tolerance graph [5].

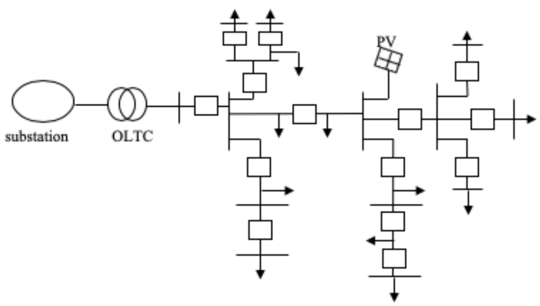


Figure(1) Voltage tolerance standard_ANSI C84.1

VII. Modeling system

A. 1.Ieee_15 bus system

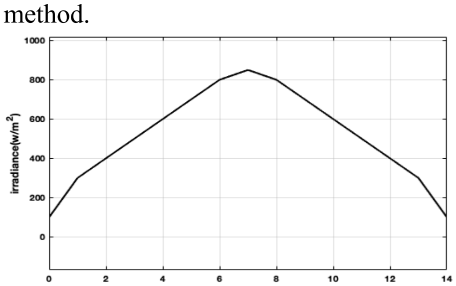
The 15-bus distribution system is used to perform the simulation. The ieee_15 bus modified test system consists of substation, grid connected PV system,15bus,14transmission lines, 2transformer and 13constant impedance load.



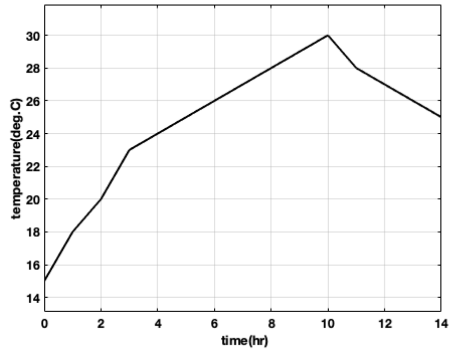
Figure(2) single line diagram for i_eee 15 bus system

B. PV system

PV power profile was obtained from 250KW PV plant. Figure (3) and (4) show PV irradiation and temperature during 14 hour which the output of PV panels is function of these two variables. the dc link is maintained by making use of maximum power point tracking algorithm(MPPT). the MPPT technique used is perturb and observe method. The inverter controls are modeled using direct quadrature (DQ)frame method.



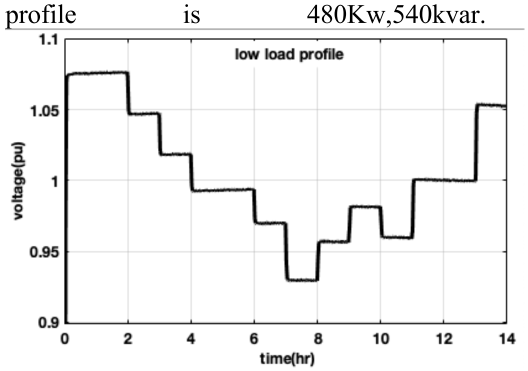
Figure(3) Solar raddiation during14hour



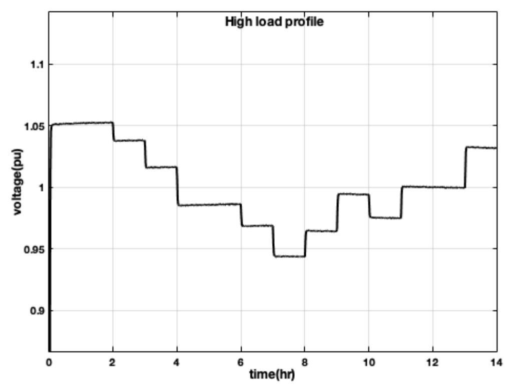
Figure(4) Temperature during14hour

C. loads

Two separate cases (high load profile and low load profile) were built as shown in figure (5) and (6) to perform the simulation. 1Mw,0.95Mvar represent the peak value of high load. While the peak value of low load profile is 480Kw,540kvar.



Figure(5) voltage profile for high load



Figure(6) voltage profile for low load

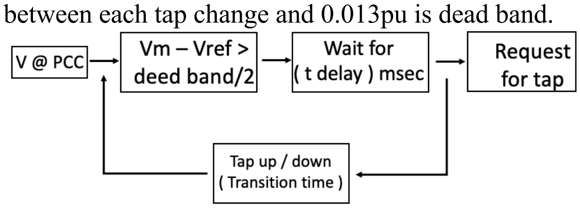
IV. Voltage regulation devices

A. . Smart PV inverter

Developing power electronics made it possible for PV inverter to regulate the voltage. This smart inverter may bring significant improvements to the reliability, stability and power quality of the electric power distribution system [6]. Since inverters are required to operate with generating zero reactive power, the iq which determine the reactive current of inverter can be set to zero. In this study, set point voltage, constant power factor, constant reactive power, German law voltage interconnection Std. Curve, Voltage_reactive power curve and Voltage_ power factor curve are the PV inverter methods simulated to regulate the voltage at the PCC. The rating of the inverter of PV is 1MVA.

B. On Load Tap Changer

It becomes very complicated to regulate the voltage by OLTC with PV penetration because the voltage level varies with PV power generation. OLTC also known as on circuit tap changer which is the main device of distribution transformer. It can ensure the power supply quality and regulate the voltage or phase shift by varying the ratio while the transformer carrying load. However, mechanical OLTC has some disadvantages, such as the big size, complicated structure, slower action speed, arc caused by switching and disability to accurate control[7][8][9]. The OLTC has several connection points across the high voltage winding connected to the taps. each of this taps refers to a certain turns ratio. The output voltage of transformer can be varied by changing turns ratio of winding[10]. Tap selection time slow down the mechanical process(4sec per tap). As time delay is set to avoid the operation of tap changer due to dynamic response of OLTC mechanism. The dead band is set to prevent unnecessary adjustment for small voltage variation at PCC. The transformer operates based on a voltage range on point of measurement. If the voltage at the PCC is out of range for time greater than delay time (sec), a request for tap change is made then the transformer adjusts its tap to regulate the voltage. The On Load Tap Changer uses a tapped winding (regulation winding) in series with winding 1(Yg) to vary the U1 voltage in 16 Delta steps from tap -8 to +8 (17 positions). Tap position 0 corresponds to nominal voltage ratio. Figure (7) shows the block diagram of OLTC operation. The OLTC is set to regulate the voltage near to PV plant. Each step having a regulation of 0.0095pu of voltage with 1 second as a delay time between each tap change and 0.013pu is dead band.



Figure(7) block diagram of OLTC

V. Simulations

- *Study cases*

To study the interaction between OLTC and PV inverter on ieee_15 bus system there is some simulations were conducted. The following section will describe simulations conducted and their observations

A. Case1- With high load profile

I. Scenario1-Independent voltage regulation by OLTC and smart PV inverter.

I.1 OLTC only

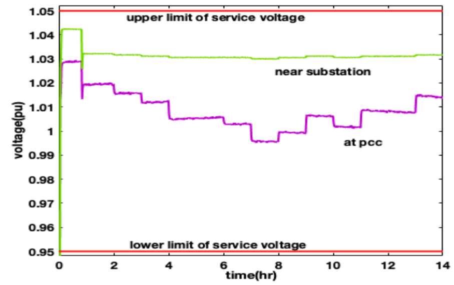
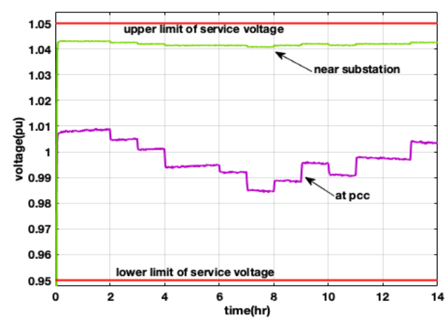


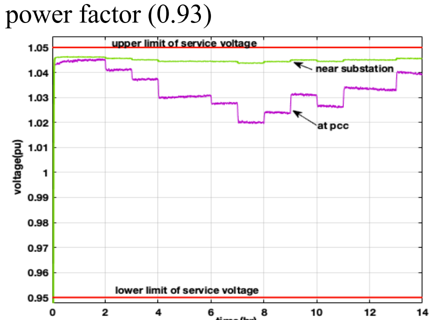
Figure (8) Voltage regulation by OLTC only caseI.1.

As observed in the unregulated high voltage profile, the voltage get out lower limit and thus voltage regulation is required. Figure (8) shows the regulated voltage profile due to the operation of OLTC.The transformer has a request for tap changes at start up to set the voltage within limits. When the OLTC taped it appear in voltage profile and the voltage changed roughly. the number of oltc tapinng is (2taps).

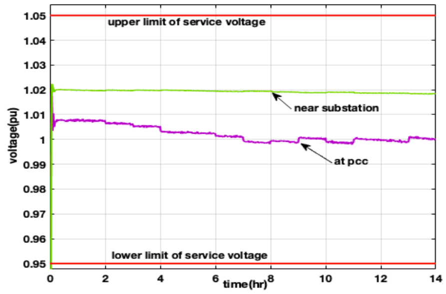
I.2 Smart PV inverter only.



Voltage regulation by smart inverter with constant power factor (0.93)



Voltage regulation by smart inverter with constant reactive power(400KVAR)



Voltage regulation by smart inverter with constant voltage(1pu)

Figure (9) Voltage regulation by smart PV inverter caseI.2

In this case, the pv inverter is set to operate in old voltage control methods. Real power priority is selected. Figure (9) shows the voltage profile at constant pf, constant VAR and constant V. Allowing PV inverter to regulate the voltage has appositive impact in pulling the voltage profile within limits.

II. Scenario 2-Simultaneous voltage regulation by oltc and pv inverter.

In this case the OLTC and the smart PV inverter will be allowed to regulate the voltage. As shown in table (I) the number of OLTC operation increased when the PV inverter contributing to voltage regulation where the wrost case is with constant power factor and the best case is with constant var.

TABLE I NUMBER OF OLTC OPERATION-CASE1.I

Case study:	**No of oltc taping:**
Const pf	26
Const var	16
Const v	23
German law curve	24
Voltage_var curve	20
Voltage power factor curve	19

B. Case2- With low load profile

I. Scenario1-Independent voltage regulation by OLTC and smart PV inverter.

I.1 OLTC only

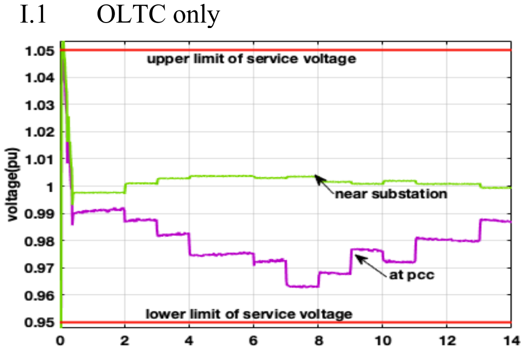
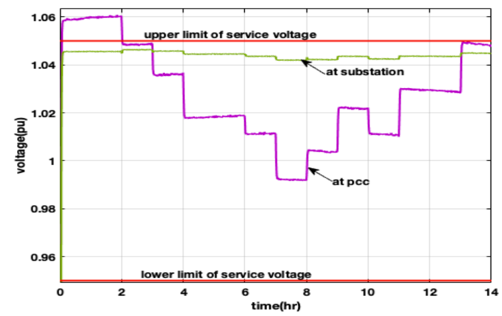


Figure (10) Voltage regulation by OLTC only case2.

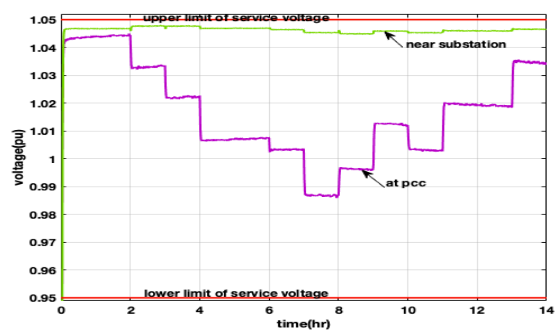
the figure (10) shows voltage profile for 14hr simulation with OLTC only.It can be seen that the voltage near substation and at pcc is within ANSI_C48.1 limit. the number of oltc taping is (8 tap).

I.2 Smart PV inverter only.

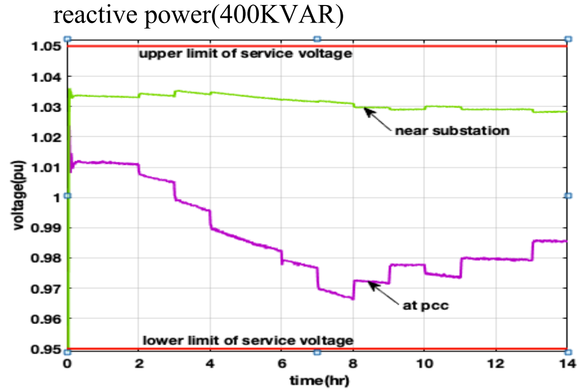
Figure (11) shows low load profile with old methods of pv inverter. It can be fined that at constant power factor with low load profile the voltage at the first is still out of limits. But with constant reactive power and constant voltage the voltage gets within limit.



Voltage regulation by smart inverter with constant power factor (0.93)



Voltage regulation by smart inverter with constant reactive power(400KVAR)



Voltage regulation by smart inverter with constant voltage(1pu)

Figure (11) Voltage regulation by smart PV inverter caseI.2

II. Scenario2-Simultaneous voltage regulation by OLTC and PV inverter.

The OLTC and the smart PV inverter will be allowed to regulate the voltage like CASE1.II. As shown in table II also the number of OLTC operation increased when the PV inverter contributing to voltage regulation where the worst case is with constant voltage method and the best case is with voltage_var curve method. It can be seen that the impact of pv is appear clearly with low load than high load because with high load the load can absorb the extra power.

TABLE II NUMBER OF OLTC OPERATION-CASE2.II

Case study:	No of oltc taping:
Const pf	28
Const var	29
Const v	37
German law curve	26
Voltage_var curve	24
Voltage power factor curve	28

VI. Conclusions and future work

This study focuses on the interaction of OLTC as traditional voltage regulating equipment with smart PV inverter controlling the voltage at PCC with two different load profile. Different case studies were performed and presented using different PV inverter modes. The cases studied the effect of allowing pv inverter to contribute to voltage regulation of the system and its impact on the operation of OLTC. The results showed that allowing pv inverter to regulate voltage may not decrease stress on OLTC but may increase OLTC operation. The different mode of pv inverter gets different interaction with OLTC under different loads profile that lead to say the impact of PV integration are influenced by variety of variables other than system loading and type of control algorithm. Which leads to conclusion that voltage regulating equipment have to be coordinated to minimize the operation of OLTC while maintaining appropriate voltage levels and each system is unique and may require special studies.

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