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Three Phase Load Flow Investigations in the Context of Smart Grid

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ABSTRACT

The developments & progress in communications, information and control have revolutionized the conventional grid. Currently integration of renewable energy resources, dynamic optimization techniques, advanced performance analysis tools, monitoring and measurements are handled under the smart grid umbrella. Central and distributed generation control requires efficient load flow analysis and monitoring at both levels. Three phase load flow investigations have been carried out on three real time systems: National Transmission and Dispatch Company (NTDC), 32-Bus 500/220 kV primary Power System, the distribution systems of Islamabad Electric Supply Company (IESCO) 11 kV, 81-nodes and University of Engineering & Technology (UET), Taxila 21-nodes by simulating in MATLAB Simulink Environment. Smart Environment has been created in three systems with increasing complexity from system 1 to system 3 and system 3 is proposed Smart Grid Model for UET Taxila. NTDC primary network has been analyzed with the integration of Renewable Energy Resources (RERs), Static Var Compensators (SVC) and IESCO distribution network subject to RERs, Distribution Static Compensation (D-STATCOM) with monitoring of parameters at control Centre in both cases. System 3 is simulated with Solar Integration, D-STATCOM, Electric Fuel Cell Vehicle (FCV), Intelligent Distribution Boards (DBs), and monitoring through Transmission Communication Protocol over Internet Protocol (TCP/IP) in control Centre. Idea of smart DBs is proposed and implemented for load management. The simulation results of three-phase Load Flow Analysis successfully proved its potential strength for smart environment.

1. Introduction

The developments in the present grid are being visioned in the light of the concept of Smart Grid (SG). The term “smart grid” defines a self - healing network equipped with dynamic optimization techniques that use real-time measurements to minimize network losses, maintain voltage levels, increase reliability, and improve asset management.

The existing tools and techniques used in the power system are being revisited in the light of the SG concept. Currently some of the active areas of research include SG communication & measurement technologies, performance analysis, stability analysis techniques and computational tools for SG design.

The conventional methodologies for power flow analysis, that are generally used in transmission networks, as Newton Raphson and Fast Decoupled [1, 2], typically show poor performance when applied to distribution systems. Low R/X ratio, unbalanced loads between phases, large number of nodes and the presence of DGs leads these problems to poor convergence [3]. In single phase LFA assumptions are made for balanced power system and balanced system model [4]. In many cases unbalance system cannot be ignored due to un-transposed transmission circuits and unbalanced loadings in distribution systems. So three-phase load flow analysis is a useful tool to resolve such issues.

Unbalanced power systems can be modeled using phase components and sequence components. But in case of sequence components the size of the problem is successfully reduced as compared to phase components approach [5, 6]. In Newton Raphson load flow analysis problem size is reduced from a 6x6 to 2x2 Jacobian matrix using sequence component methodology. As positive, negative and zero sequence components can be solved in parallel computations [7-9].

With the integration of RERs, there are DC/AC interconnections which lead to asymmetry and unbalanced loading [10], consequently three phase load flow is the potential tool under such conditions. The rest of the paper is organized as: section 2 deals with three phase load flow, section 3 covers Smart environment, section 4 presents case studies and lastly the conclusion.

1.1. Three Phase Load Flow Analysis

The single phase load flow solution provides fast convergence for large transmission networks. Currently three-phase load flow is treated simply as an extension of the single phase load flow. It is primarily used to calculate asymmetry throughout the transmission circuits. The load

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flow is more suited to the analysis of unbalance real time conditions in the transmission line Three-phase load flows have followed a succession from non decoupled system to decoupled systems. In decoupled systems, there exist decoupling between phase and sequence components. The decoupled method is faster than a pure Newton solution by a constant factor, independent of the network size. Size of Jacobian Matrix is successfully reduced in sequence component approach. So Three Phase LFA exploiting the strength of sequence component approach is useful tool to supervise the performance of SG. The main advantage of this method is that it is easy to implement and compatible with any existing load flow solution methodology. The objective of a three phase load flow is to solve for zero and negative sequence voltages and currents [11, 12].

2. Smart Environment

Current power grid was planned to function as a vertical structure consisting of generation, transmission and distribution, and supported with devices to maintain reliability, stability, and efficiency. However, grid operators are now facing new challenges including the penetration of RERs in the conventional system, rapid technological changing's and different types of market players and end user consumers participation. The smart grid will be equipped with communication support schemes and real time measurement techniques to protect against internal and external hazards. The design framework of the smart grid environment is based upon unbundling and streamlining of power sector and optimizing its assets. The design and progress of the smart grid require modeling of sustainable energy resources and technologies such as wind, solar and fuel cells for clean and modern grid initiative. Technological changes are being driven by the introduction of emerging technologies and energy management. The market driven power business environment has created an open access of research. In this paper, three phase load flow investigations are carried out and Smart Environment has been created in three systems with increasing complexity of transmission, distribution network and a UET Taxila distribution feeder.

National transmission and dispatch company (NTDC) links the power generation units and load centers dotting the entire country, thus creating one of the largest contiguous grid systems. At present NTDC is operating and maintaining nine 500 kV and twenty four 220 kV grid stations alongwith 10,167 km length of associated transmission lines [13]. The 32-bus, 500/220 kV Standard Test System [14] of NTDC network shown in Fig. 1 has been used for load flow analysis by integrating Wind, Solar Hydel and Solid oxide fuel cell plant with the conventional grid.

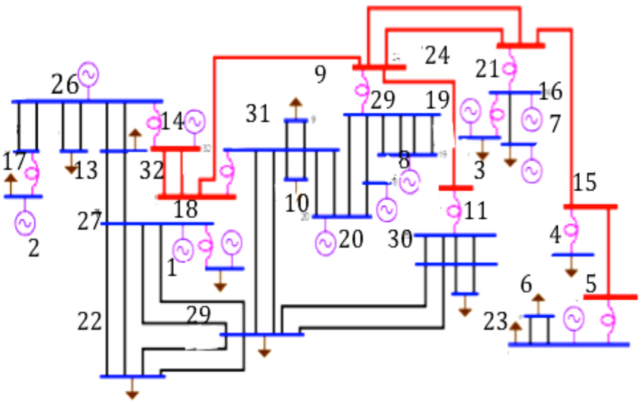

Fig. 1. One line diagram of NTDC transmission network.

IESCO 81-node, 11 kV network shown in Fig. 2 has been simulated for analysis by integrating solar unit with D-STATCOM for reactive power balance, and monitoring & measurements at the control Centre.

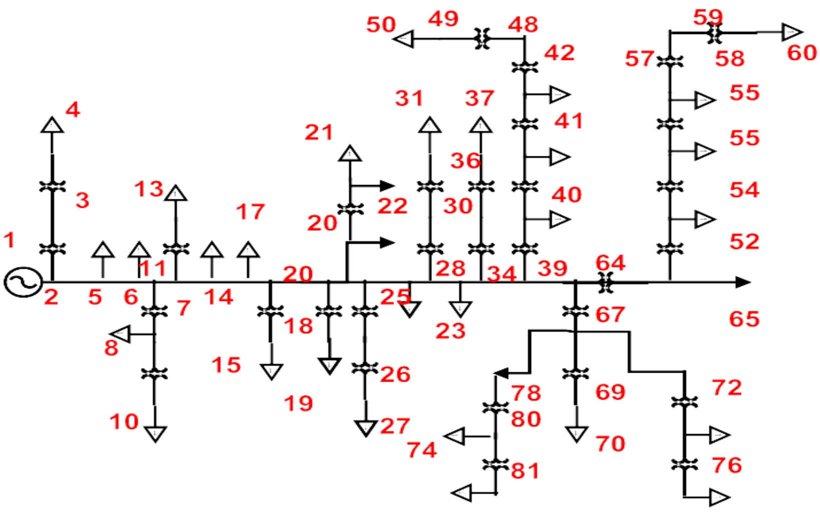

Fig. 2. One line diagram of distribution system.

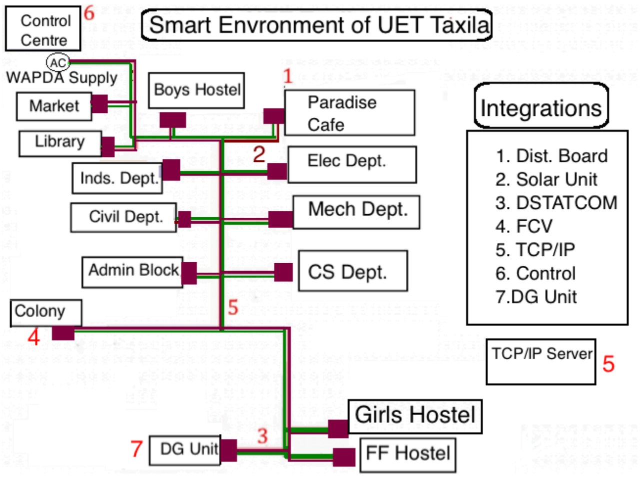

Fig. 3. Smart environment for UET Taxila distribution feeder.

UET, Taxila 21-node distribution system is proposed smart grid environment shown in Fig. 3. The proposed model has green power in form of Solar Unit, D-STATCOM integration to balance the reactive power flow and facility of give and take of energy from the system in the form of hybrid electric vehicle. The deployment of electric vehicle potentially has a substantial positive impact on the electric power system from the point of view of increasing electric energy consumption and compensating fuels with alternative sources of energy. For monitoring of grid health, control Centre has been established. TCP/IP communication medium has implemented for load flow parameters monitoring and measurements. Intelligent D.B concept is introduced for load management during shortfall.

3. Smart Environment for UET, Taxila

Three phase load flow analysis of UET, Taxila distribution feeder is carried out in smart environment. The description of major components of smart environment is given below.

3.1 Control Centre

It is the operational center for monitoring of departmental load and other load activities. At this point Voltage, angle, frequency, active power and reactive power are monitored. D-STATCOM and other integrated devices are also controlled here.

3.2. Distribution Boards

In Distribution boards, the main departmental load is distributed into three sections i.e. labs load, lightening load and air conditioning load. When there is a shortage of supply, the priority selector in D.Bs entertains the load according to the predefined priority order of the three load sections. For example the lightening load has higher priority over labs and air conditioning loads and is thus entertained first. The priority selector is shown in Fig. 4a & 4b.

3.3 TCP/IP Communication

In MATLAB/Simulink, TCP/IP is applied for communication with remote applications using Simulink blocks provided by the toolbox. These blocks enable to query an application using TCP/IP to incorporate live data into model and to send live data from Simulink model to an application. It works over LXI (LAN extensions for Instrumentation) which defines a standard for communicating with instruments over Ethernet. IEEE 802 series of standards is considered as base communication. Simulink modeling of TCP/IP is presented in Fig. 5.

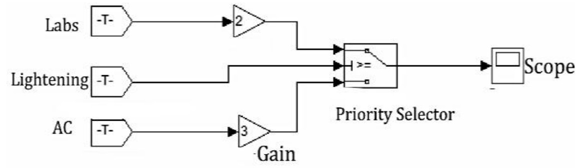

Fig. 4a. Distribution board.

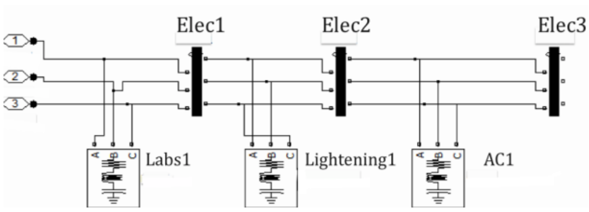

Fig. 4b. Distribution board.

3.4 Solar Unit

Solar unit of 200 kW is integrated in electrical engineering department. As the purity of sine wave is affected due to DC/AC conversion in the solar unit, VAR compensation is incorporated in the circuit to improve the output voltage. Block diagram of system is shown in Fig. 8.

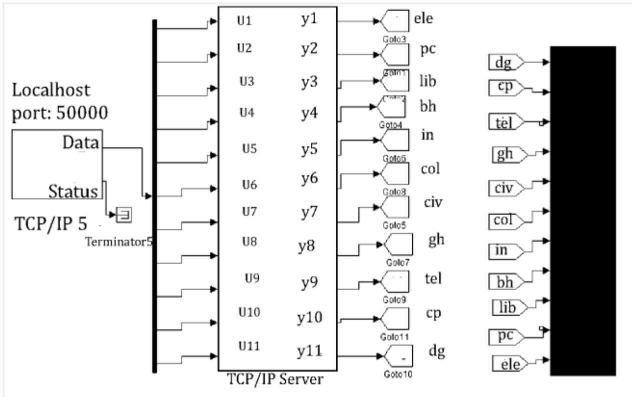

Fig. 5. TCP/IP communication network.

Solar unit of 200 kW is integrated in electrical engineering department. As the purity of sine wave is affected due to DC/AC conversion in the solar unit, VAR compensation is incorporated in the circuit to improve the output voltage. Block diagram of system is shown in Fig. 6.

3.5 D-STATCOM Integration

To handle the reactive power losses D-STATCOM is integrated in the system to improve the voltage and reactive power. [9] The reactive power is absorbed, in case of excess and provided, in case of shortage, in D-STATCOM. The output of solar Unit, with and without D-STATCOM integration, can be seen in Figs. 7 and 8 respectively.

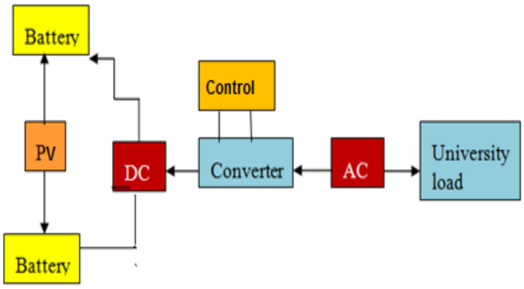

Fig. 6. Block diagram of solar integration.

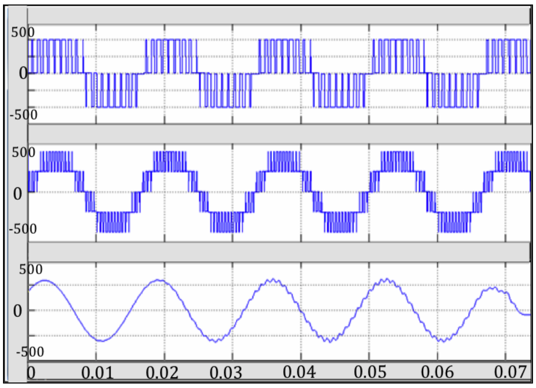

Fig. 7 Solar Output without D-STATCOM.

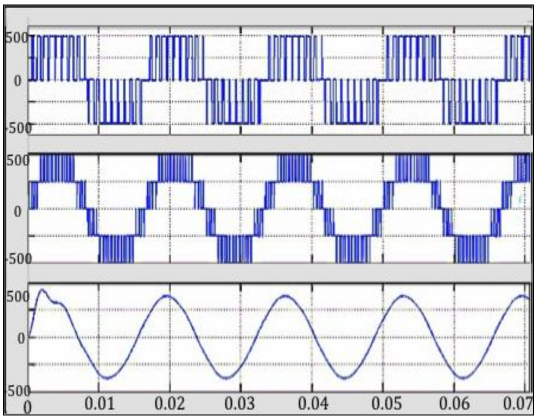

Fig. 8. Solar output with D-STATCOM.

3.6 Integration of Fuel Cell Electric Vehicle

The FCV electrical subsystem is composed of four parts: electrical motor, storage battery, fuel cell unit and AC/DC converter. The hybrid vehicle dynamics subsystem models all mechanical stuff of the vehicle. The energy management subsystem determines the reference signals for the electric motor drives, the fuel cell system and the converter in order to distribute correctly the power from the two electrical sources. These signals are calculated using mainly the position of the accelerator, which is between 100% and 100%, and the measured fuel cell vehicle speed.

Case Studies

Three phase load flow investigations have been performed for three test systems.

4.1 Test System 1: NTDC Network

Three Phase Load flow analysis of 500/220 kV, 32-bus NTDC network is carried out. The networks consists of twelve 500 kV and twenty nine 220 kV lines.

4.1.1 Data Preparation

Standard data has been collected for power flow analysis. The bus bar data has been prepared with the generation loading conditions at peak hour. Transmission lines data has been prepared in form of sequence components. The sequence components of all transmission lines are calculated.

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4.1.2 Observations for Base Case

- Voltages calculated at busses are approximately in agreement with the SCADA system results.
- Low voltages at buses Yousafwala, Burhan, Mardan, KSKU and Gakher are correct in the sense that Voltage at these buses in NTDC system is depressed.
- Var generation at the buses is within the maximum and minimum limits except Mangla.
- The Equation Generation=Load + losses is satisfied for active power as well as for reactive power.
- Some lines are heavily loaded due to the increased load demand.
- Reactive power losses are high at some heavily populated areas e.g. KSKU.

4.1.3 Observations for Smart Environment

Three Phase Load flow analysis of 500/220 kV, 32-bus network is carried out with wind Unit at Jamshoro, Solar Unit at Multan, Hydel Unit at Kot-Addu and Fuel cell power plant at Faisalabad. SVC is integrated to balance the reactive power flow in the system. SVC has near instantaneous response to adjust the system voltage [8]. So it maximizes the reactive power and it can rapidly provide reactive power when required. LF parameters are monitored at remote ends and at the control unit. Following objectives are achieved.

- Lines are relaxed as total generation is increased.
- Active power losses are reduced (Up to 31MW).
- Var generation in power house is in maximum and minimum limits except mangla.
- Voltage is improved specially at Bus 10, 15, 18 and 31.
- Reactive power is balanced due to SVC integration.

4.2 Test system 2: IESCO Distribution System

Three Phase Load flow analysis of 11 kV, 81-bus IESCO network is carried out. The sequence components of all transmission lines are calculated.

4.2.1 Conventional Distribution System as Base Case

- Voltage profile is average, exceeding the limits at some nodes.
- Lines loading at some points in the system are high due to overloaded transformers e.g. at node 34.
- Imbalance in reactive power flow is also observed.

4.2.2 Smart Distribution System

11 kV, 81-bus IESCO distribution system is simulated with RERs integration. D-STATCOM is integrated in the middle of the distribution network to control reactive power flow of the system. A solar unit is also added in the lateral branch of the system. System Monitoring and measurements of LF parameters at control Centre as well as at the remote ends are carried out. Voltages at busses are improved as compared to the base case.

- Lines are relaxed because of increase in generation.
- Active and reactive power losses are reduced.
- With Addition of D-STATCOM reactive power is balanced.

Overloaded transformers are now in prescribed loading limits.

4.3 Test System 3: UET Taxila Distribution Feeder

In this study, design of Smart environment is proposed for UET Taxila distribution feeder with solar and D-STATCOM integration. D-STATCOM provides control of voltage, balance of reactive power generation/ consumption and optimal line flow activities. Fuel cell electric vehicle is plugged in to the system. Control Centre deals with monitoring of components on site and remote ends via TCP/IP. With all these integrations the voltage profile of system leads to unity and power losses are reduced.

5. Results & Discussion

At transmission level, by investing new technologies in conventional grid a smart environment is created. The improvement in the voltage profile can be seen in Figs. 9 and 10.

Active power losses have been reduced from 547MW to 533MW and the Reactive power losses from -109 MVAr to -101 MVAr.

Table 1. Three phase LFA case studies.

Three-Phase LFA	Base case	Smart Environment
Transmission level 500/220 kV 32-bus NTDC Network	Conventional system without monitoring & measurements Without RERs	Integration of Wind unit Integration of solar unit Integration of fuel cell plant Monitoring at control Centre and remote ends Integration of SVC
Distribution Level 11kV/440V 81-bus DISCO Network	Conventional system without monitoring & measurements Without RERs	Integration of solar unit Integration of D-STATCOM Monitoring and measurements of LF parameters
Sub Distribution Level UET TAXILA Distribution Feeder	Conventional system without monitoring & measurements Without RERs	Design of Control Centre Intelligent Distribution Board TCP/IP Communication Network Solar Integration Integration of Electric vehicle D-STATCOM Integration Monitoring and Measurement at remote end and control Centre Distributed Generation unit

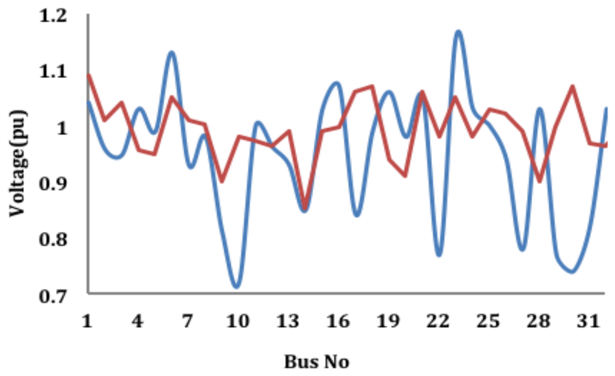

Fig. 9. Voltage profile comparison of transmission system.

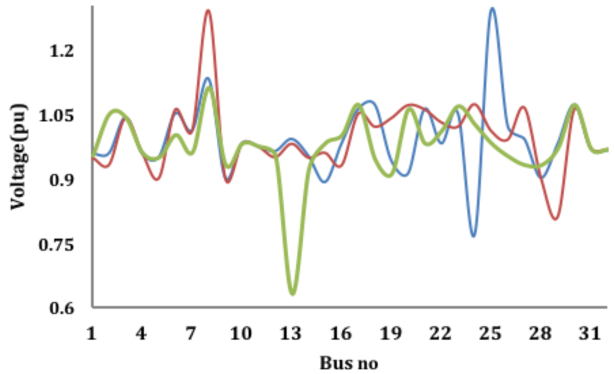

Fig. 10. Voltage profile of three phases.

At distribution level, the smart environment leads to voltage profile improvement and the reduction in active and reactive power losses as indicated in Figs. 11 and 12. The comparison of phase voltages is shown in Fig. 13.

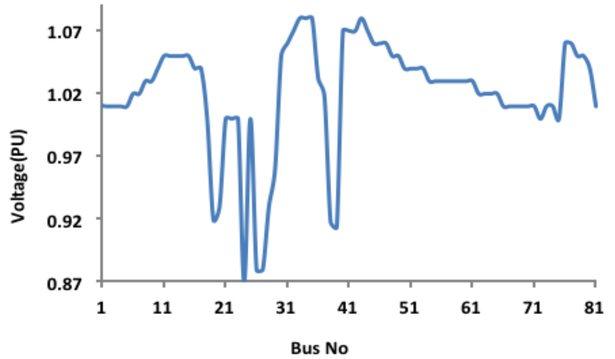

Fig. 11. Voltage profile comparison of distribution system Base Case.

For Distribution System, Active power losses have been reduced from 303MW to 213MW and the Reactive power losses from -192 MVAr to -92 MVAr.

For UET, Taxila distribution feeder, experimentations have been carried out for a proposed smart environment.

Voltage profile improvement, two-way communication, reduction of losses, wireless monitoring and smart load

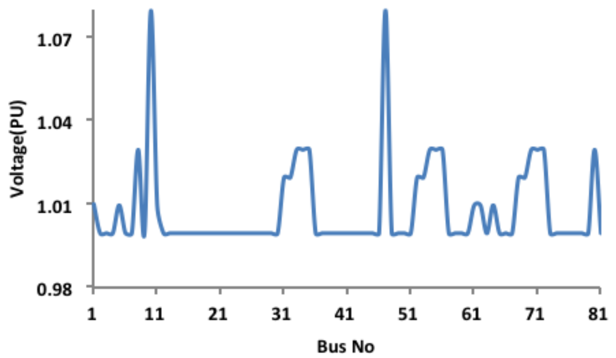

Fig. 12. Voltage profile comparison of distribution system with Solar and D-STATCOM integration.

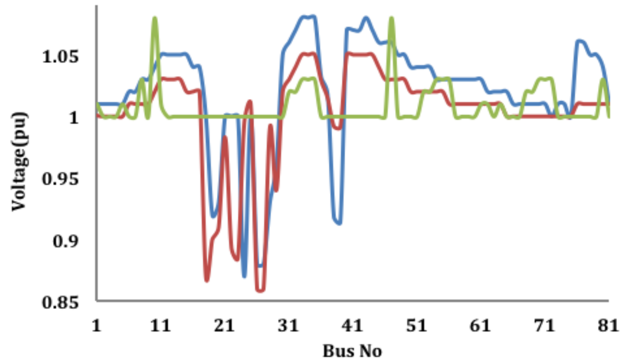

Fig. 13. Comparison of phase voltages.

management system are major attributes of the proposed test bed. Voltage Profile comparison has been presented in Fig. 14 and 15.

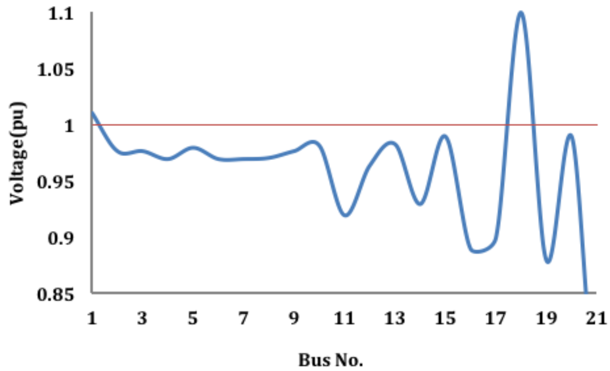

Fig. 14. Volt profile comparison of UET Taxila.

6. Conclusion

The combination of conventional technologies with advanced smart grid elements, that optimize and enhance the value of network investments, has been explained. While working in smart environment efficient performance analysis tools are required; conventionally balanced single phase load flow techniques are in practice. In case of smart environment, three phase load flow investigations are carried out at transmission, distribution and UET, Taxila sub distribution feeder, as system imbalance loading conditions cannot be ignored.

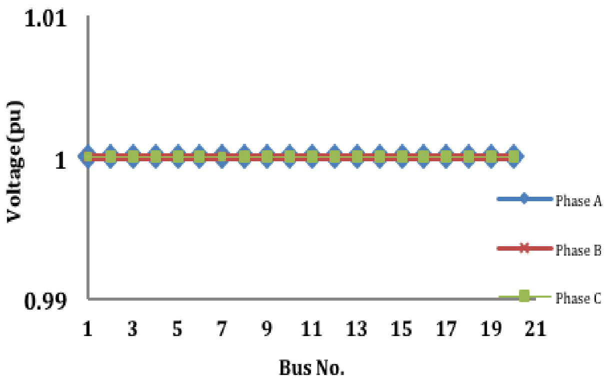

Fig. 15. Comparison of phase voltages.

The work is primarily directed to the preparation of smart grid demonstration, mainly in terms of structural development and the assessment of new intelligent performance analysis tool in smart environment. Proposed smart grid model deals with wireless communication, three phase load flow information monitoring, development of control Centre, incorporation of FACTs device, RER integration, smart load management strategy and consumer participation via plugged in fuel cell electric vehicle. The simulation results of three-phase load flow analysis successfully validate the strength of proposed smart environment.

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