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IMPACT OF DGS POWER FACTOR ON VOLTAGE PROFILE AND POWER LOSSES OF DISTRIBUTION NETWORK

A. Gill [1] A. Choudhary [2] H. Bali [2] A. Kalwar [3]

1. Department of Electrical Engineering, JECRC University, Jaipur, India, aamangill.87@gmail.com
2. Department of ECE, JECRC University, Jaipur, India, abhilasha@jecrcu.edu.in, himani.bali@jecrcu.edu.in
3. Department of Computer Science and Engineering, JECRC University, Jaipur, India, anju.kalwar@gmail.com

Abstract- Distributed generations (DGs) are the need of the current situation for fulfilling the increasing demand for the power supply. DGs are treated as sources for power supply, therefore penetrated in the distribution networks on fit and forgot strategy. Currently, DGs usually not involved in the voltage control of the distribution system. Hence, DGs will typically pick to run at unity power factor to reduce their electric losses and stay clear of any charges for reactive power usage, whether the network needs it or not. The effect of DGs power factor on the distribution network's voltage profile and power losses is shown. A 7 bus/node distribution network is considered for the penetration of distributed generator (DG) at different power factors and its effect on the voltage profile and power losses at peak and minimal load.

Keywords: Distributed Generator (DG), Distributed Generations (DGs), Synchronous Generator (SG), Induction Generator (IG), Photo Voltaic (PV).

1. INTRODUCTION

Conventionally, the flow of power is from the transmission to the distribution network (DN) and further distributed to the consumers. The power transfer was from a higher to lower voltage profile (VP), displayed in Figure 1.

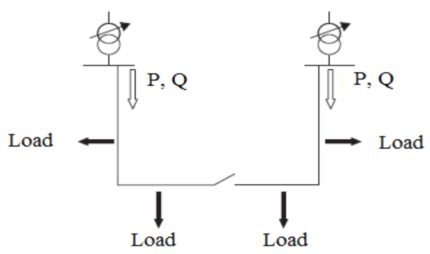

Figure 1. Traditional Distribution Network [1]

With the significant infiltration of distributed generations (DGs), the flow of power becomes bidirectional from unidirectional, and the distribution system has transformed into an active system from a passive system, as shown in Figure 2.

The synchronous generator (SG) in combined and heat power (CHP) plant will transfer real power when the electric load of the facilities dips below the SG's outcome; however, it may supply or consume reactive power (RP) based upon the setup of the SG excitation. The fixed-rate wind generator will supply active power and consumes RP as its induction generator (IG) calls for a resource of RP to run. The photovoltaic (PV) supplies the active power at a fixed power factor (PF) but with harmonic currents [1].

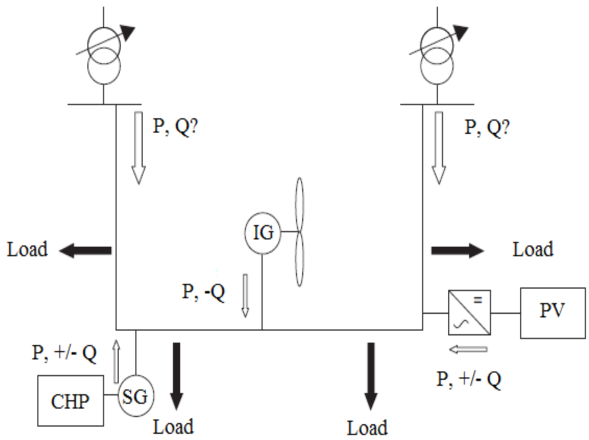

Figure 2. Distribution Network with DGs Penetration [1]

The change in power flows from unidirectional to bidirectional caused by DGs has essential technological ramifications for the DN. Earlier in case of DGs, most interests were on the penetration and operation in a distribution network. Most countries created criteria and techniques to take care of these. Generally, the methods were to maintain the quality of supply voltage after DGs penetration and the DGs were considered a negative load. The approach was of fitting and forgetting the DGs in the DN. The DN's design and creation were to ensure that it worked correctly for all combinations of generation and load without any controlling action by the DGs [2]. Recently, researchers are working on optimal penetration [3], coordination and protection [4] of renewable DGs [5] in the DN.

2. TYPES OF DGS TECHNOLOGIES

Some of the most common DGs technologies are shown in Figure 3.

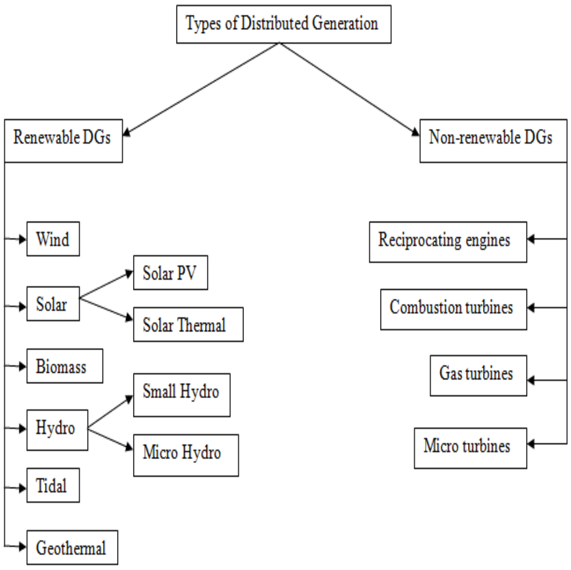

Figure 3. Types of DGs [6]

2.1. Synchronous Generators

The big power generation plants generally utilize synchronous generators. Typically, highly efficient permanent magnet synchronous generators are not located in big power plants. These are utilized in some variable-speed wind power plants and micro-generators. Small generators cannot impact the frequency of the big interconnected network. In small power networks, change in total network load or blackouts on the large generating network will certainly cause considerable frequency modifications. The governor droop characteristic makes a traditional approach to regulate the power outcome of a generator. Figure 4 changes in frequency shown by the line *xy* needed to transform the generator's power outcome from no load to full load.

At one per unit (p.u) frequency, the generator produces power P_1. If the frequency decreases by one per cent the, power outcome rise to P_3, and if the frequency increases by one per cent, the power outcome decreases to P_2. It is precisely the behaviour needed from a big generator that can affect the system frequency; if the frequency goes down, more power is called for while if the frequency rises much less power is needed. The position of the line *xy* can be altered along the vertical axis; therefore, by relocating the line to x_0y_0. The power result can be restored to P_1 despite a raised network frequency or by relocating to x_1y_1 for a minimized network frequency.

Quadrature droop characteristic is the system voltage versus reactive output power for generator excitation control for controlling system voltage, as shown in Figure 5. For line *xy* at 1 p.u voltage, no reactive power is traded with the system at Q_1. If the system voltage increases by one per cent, then the system transfers to Q_2 and the generator imports the reactive power to manage the voltage surge. If the system voltage goes down to Q_3, the generator exports the reactive power to the system. By shifting the lines to x_0y_0 or x_1y_1 operating point can be managed at Q_1 despite an increase or decrease in the voltage. These controllers (governor and automatic voltage regulator) must maintain system variables like frequency and voltage for bigger synchronous generators. Still, they are not suitable for small synchronous DGs systems.

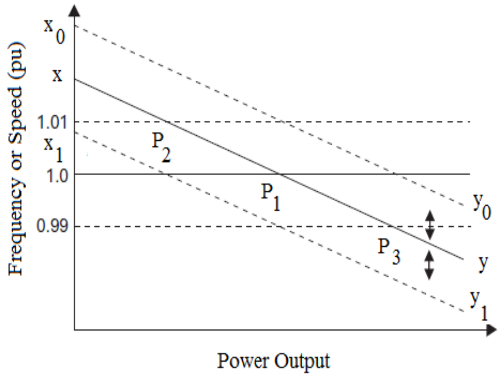

Figure 4. Governor Droop Characteristic for Generator Governor Control [6]

For example, CHP prefers to work at a set power outcome or exchanges fix power with the system, regardless of network frequency. Similarly, a procedure without reactive power exchange with the system might be preferable to reduce the RP charge. Suppose the generators are operating on the above-discussed droop features, then with the system's change in voltage and frequency due to outside influences. In that case, the generator's real and reactive power outcomes will alter constantly.

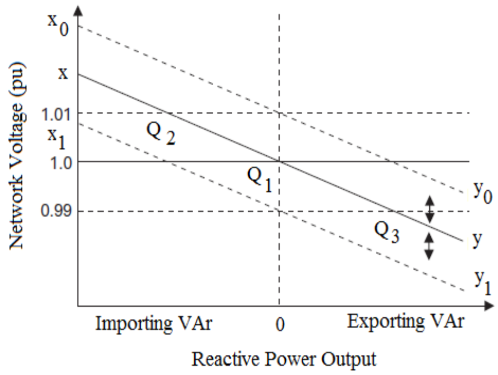

Figure 5. Quadrature Droop Characteristic for Generator Excitation Control [6]

For small synchronous DGs system attached with the network, system control depends on the real and reactive power outcome instead of on frequency and low voltage for huge generators. To control the generator's real power output, the governor controls the steam supplied to the turbine. To control the generator's RP output, the automatic voltage regulator or exciter controls the field current. So, the real power outcome is controlled to a set point regardless of the frequency of the network, while the reactive power is controlled to a certain value or power factor regardless of system voltage.

Clearly, for relatively large DGs system or groups of small-sized DGs system affect the system, so it should have proper supply voltage assistance technique. These techniques made use of any place a generator has a considerable influence on the network. Still, there is a concern of just how to influence the DGs system owners to apply them. DGs not operating at unity PF boost the generator's electrical losses while differing true power outcome in reaction to system frequency will have ramifications for the steam supply and prime mover. Enhancing numbers of small DGs systems are connected to the power system and must collaborate their reaction both to steady-state and faulty power system conditions. This demand for the DGs to give system support is currently evident in the grid codes for transmission system connection, applied to the big wind power plant connected to network. So, large wind power plant operates under voltage control to preserve voltage specifically throughout system disruptions and additionally can contribute to network frequency action [6].

2.2. Induction Generators

Squirrel-cage induction generator devices are located in a range of kinds of the small DGs system as well as are always used in constant-speed wind power generators due to the damping provided by them to the drive train. Construction vice is simple, robust and requires no synchronizing. Wound rotor induction generators are utilized in some expert DGs systems, especially with changing slip, where the external circuit changes the rotor resistance. It is also used in the doubly-fed speed varying wind power generators, where power electronic devices regulate the power circulation. With the increase in the induction generator's size, their slip reduces, and transient nature becomes the same as of SG. Also, Induction generators are utilized for the small hydropower generating plants. A PF correcting capacitor is applied at an induction generator terminal for improving the power factor [7].

2.3. Diesel Generator

It is one of the most plainly utilized DGs innovations, and it is appropriate for the stand-alone procedure. Additionally, it is turned on and turned off rapidly.

2.4. Micro Turbines

Micro turbines are small electrical generators varying from 15 kW to 500 kW. The relevance of Micro-turbines is that they are developed for business applications. There is a reduction in exhausts when contrasted to big range generators.

2.5. Photovoltaic

Photovoltaic innovations transform solar radiation right into electron current utilizing semiconductor tools. Whenever subjected to adequate light, solar cells generate direct current (DC) power of about 0.5 V. To get more power outcome; numerous solar cells are linked in series connection. Inverter circuits are made to convert DC outcome acquired by Photovoltaic cell into alternating current outcome. For DGs, Photovoltaic provides a distinctive benefit over various other kinds of generations. Regardless of the high expense of instalment at first, sunlight is free as well as it is likewise readily available in remote areas. They neither create noise nor produce any contamination in the atmosphere.

2.6. Wind Turbines

One of the most preferred renewable electrical resources worldwide are wind turbines (WT). WT includes turbine blades, rotor, generator, shaft as well as combining tools. WT incorporated into the transmission voltage degree to make wind ranches. Wind ranches that are little in dimension are ideal for distribution voltage degree and are taken into consideration for DGs. The significant advantages of electricity from wind generation are without fuel expense.

2.7. Micro Hydro

Micro-hydro is a kind of hydroelectric power that commonly generates from 5 kW to 100 kW of electrical power utilizing the all-natural circulation of water. These instalments can give power to a separated house or small area or are often linked to electrical power networks, primarily where internet metering is provided [8].

3. DGS IMPACTS AND CONSTRAINTS

3.1. The Financial Influence of DGs on Distribution Network

DGs modifies the power streams in the system, therefore, will certainly change system losses. If a small DG is placed near a high load, the system losses will be lowered. However, if a large DG is at a large distance from system loads, it will enhance losses on the network.

Currently, DGs usually not involved in the voltage control of the DN. Hence, DGs will typically pick to run at unity PF to reduce their electric losses and stay clear of extra charges of reactive power usage, whether the network needs it or not. In some countries, a different strategy was created with distributed combined heat and power plants running at various power factors based on different time spans in a day [9].

3.2. Impact of DGs on Transmission Network

DG will certainly change the flow of the power of the transmission system. So, there will be a change in transmission losses, typically minimized. In some countries, the charges for using the transmission system are currently examined by measuring peak demand at the transformer, which links the transmission and distribution system. When DGs operates through the peak demand period, it minimizes the transmission system use charges.

3.3. DGs Connection to the Network

Connecting the DGs system to the distribution system requires comprehending the operation as well as control of different sorts of generation plants and frequently requires researches to assess the performance of the network with the brand-new generation, under both regular and abnormal operating problems. The generators utilized for DGs depend upon their application and energy resource. As an example, the use of a SG is for small rating diesel DG sets. In contrast, a wind generation may use an IG (squirrel-cage or fixed speed, doubly-fed). High-frequency DC sources like PV system, fuel cells or micro-turbines need power electronic converter for interfacing with the network. The performance and features of various kinds of DGs systems vary significantly.

The use of computer system programs researches the performance of power systems with DGs:

- Load flow analysis to examine the steady-state voltages at bus bars as well as power streams in the network.
- Fault analysis to examine the fault currents produced due to various kinds of faults in the network.
- Stability analysis to figure out the stability of the network and DGs connected to the network [10].

4. CONSTRAINTS FOR DGs PENETRATION

4.1. Network Voltage Adjustments

The entire DN driver has a responsibility to provide its consumers with a voltage within the specific limits (±5% of nominal). This demand typically identifies the style and resources cost of the DN. With the placement of the DGs system at the network end, the flow of power in the circuit will certainly transform, which affects the voltage profile. When the customer is at the minimum load and the output of the DGs starts reverse flowing.

In the case of a DN having light loads, Equation (1) [11] shows the rise in voltage (δV).

$$\delta V = \frac{P_r + Q_x}{V} \quad (1)$$

where, P is active power, Q is reactive power, r is resistance, x is inductive reactance and V is voltage.

Voltage must be in the range of Equation (2) [11].

$$V_{k\min} \le V_k \le V_{k\max} \quad (2)$$

where, V_{kmin} and V_{kmax} are the min and max limit of voltage at node k.

4.2. DG optimal Size Constraint

DG optimal size in MVA should be in the range of the Equation (3) [12].

$$S_{DG\max} \ge S_{DGk} \ge S_{DG\min} \quad (3)$$

where, S_{DGmax} and S_{DGmin} are the max and min limit of the apparent power of the DG at node k.

4.3. DG PF Constraint

DG PF should be in the range of Equation (4) [12].

$$PF_{DG\max} \ge PF_{DGk} \ge PF_{DG\min} \quad (4)$$

where, PF_{DGmax} and PF_{DGmin} are the max and min limit of PF of the DG at node k.

5. RESULT AND DISCUSSION

A 7 bus/node 33 kV DN is displayed in Figure 6. The central generation is linked to node 1. The 132/33 kV transformer taps the voltage at 1.003 p.u for node 2. A DG with different power factors is penetrated at node 7 to check its effect on the voltage profile (VP) and power losses (PL) of this DN.

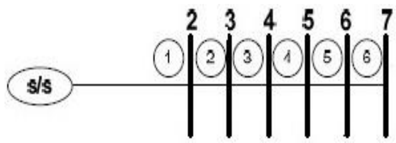

Figure 6. The 7 Node 33kV DN

A forward-backwards load flow method is applied at DN for calculating voltages, power circulations and losses at peak and minimum load. During the peak load condition, power flows from upstream to downstream using the line between nodes 2 and 3. Nonetheless, throughout the minimal load, surplus power in the circuit flows in reverse to the grid.

Table 1. Voltage profile of DN at peak load

At Peak Load	Voltage (p.u)			
	Node 3	Node 4	Node 5	Node 6
No DG	0.958	0.931	0.933	0.936
DG (Unity PF)	0.972	0.948	0.953	0.954
DG (0.9 PF lead)	0.965	0.941	0.935	0.94
DG (0.9 PF lag)	0.997	0.974	0.973	0.972

Table 2. Power losses of DN at peak load

At Peak Load	Power Losses	
	MW	MVAR
No DG	0.47	1.16
DG (Unity PF)	0.17	0.93
DG (0.9 PF lead)	0.25	1.26
DG (0.9 PF lag)	0.14	0.87

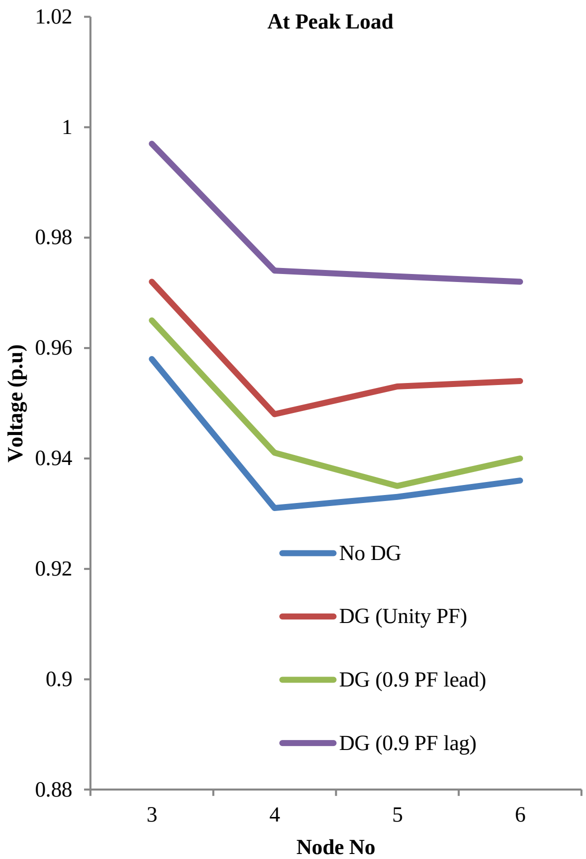

Figure 7. Voltage profile of DN at peak load

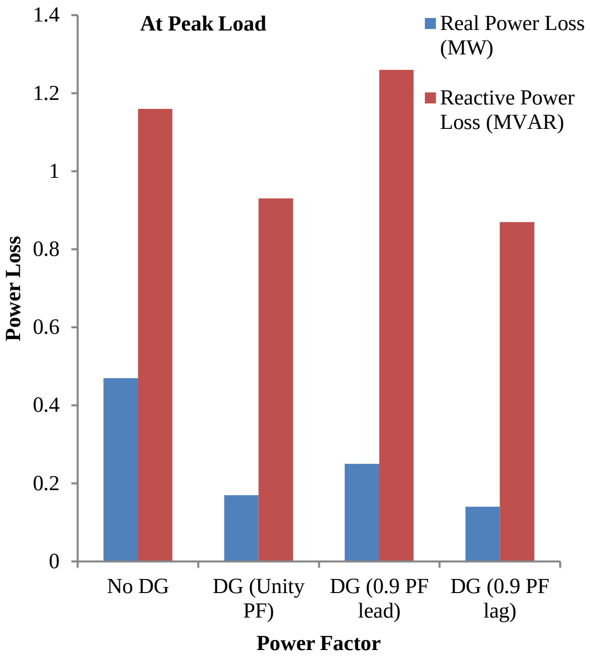

Figure 8. Power losses of DN at peak load

Tables 1 and 2, reveals the voltage profile on nodes 3, 4, 5 and 6 as well as power losses at different PF at peak load. The DN is weak the voltage profile at some nodes is under the limit (6%) without DG. DG with 0.9 PF lag has the best impact on the VP enhancement and PL reduction of DN.

Tables 3 and 4 reveal the voltage profile on nodes 3, 4, 5 and 6 as well as power losses at different PF at minimal load. DG at unity PF performs better as compared to DG at 0.9 PF lag and lead.

DG lowered the power circulation between node 2 and 3, therefore decreasing the power losses. DG at unity PF, the voltage is enhanced. Further, the voltage is enhanced by running the DG at 0.9 lag PF. The reverse holds when the DG runs at a lead PF.

At minimal load, DN without DG reveals minimal losses as well as an excellent voltage profile. With the penetration of the DG raises the voltage profiles at the nodes as well as surplus power reverse flows into the grid hence raising the power losses. So, the placement of small capacity DGs will be on low voltage overhead distribution networks.

Table 3. Voltage profile of DN at minimal load

At Minimal Load	Voltage (p.u)			
	Node 3	Node 4	Node 5	Node 6
No DG	1.001	0.998	0.995	0.996
DG (Unity PF)	1.016	1.012	1.016	1.018
DG (0.9 PF lead)	1.004	1.004	1.008	1.01
DG (0.9 PF lag)	1.03	1.022	1.025	1.029

Table 4. Power losses of DN at minimal load

At Minimal Load	Power Losses	
	MW	MVAR
No DG	0.02	0.03
DG (Unity PF)	0.14	0.86
DG (0.9 PF lead)	0.18	1.05
DG (0.9 PF lag)	0.15	0.88

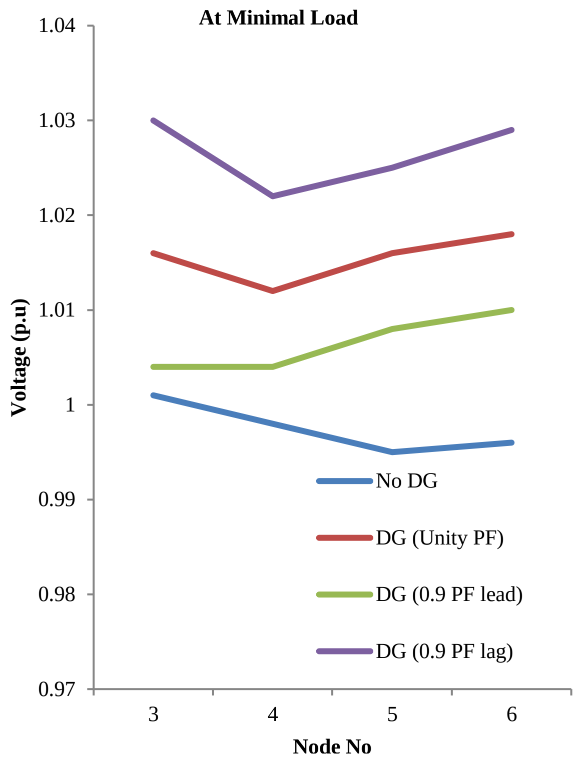

Figure 9. Voltage profile of DN at minimal load

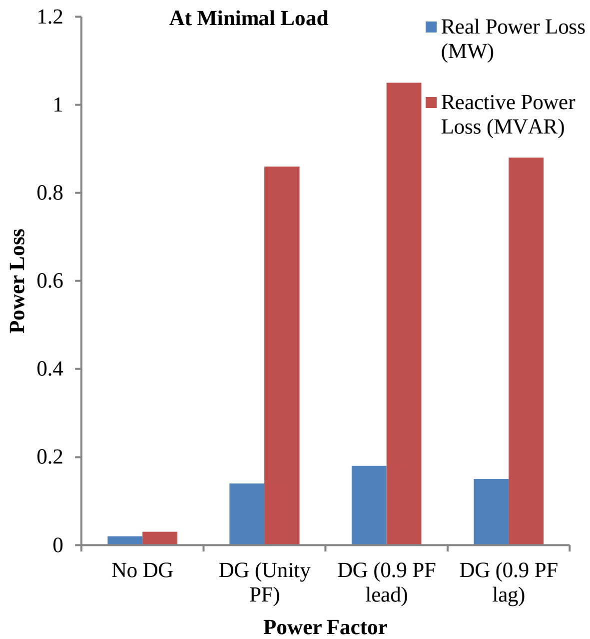

Figure 10. Power losses of DN at minimal load

6. CONCLUSIONS

DG at different PF is successfully penetrated in 7 node DN at node 7. These DGs are DG at unity PF, DG at 0.9 lag PF (exporting VARS) and DG at 0.9 lead PF (importing VARS) and the results showing the effect on VP and PL at peak and the minimal load of DN are found successfully. At peak load, DG at 0.9 lag PF has shown better results on VP enhancement and PL reduction. At minimal load DG at unity PF performs better as compared to DG at 0.9 PF lag and lead.

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BIOGRAPHIES

Amandeep Gill received his B.E. from the University of Rajasthan, Jaipur, India, M.E. from Thapar University of Patiala, Punjab, India and Ph.D. from JECRC University, Jaipur, Rajasthan, India. He is working as Assistant Professor at JECRC University. He has eight and half years of teaching experience. His research fields are Distributed generated systems, power systems, artificial intelligence, and machine learning. He has authored 4 books and has 14 research publications in SCI Journals, Scopus journals and peer-reviewed conference proceedings.

Abhilasha Choudhary received the B.Tech. in the field of ECE and M.Tech. degrees in VLSI Design both from Mody University, Lakashmangarh, India and the Ph.D. degree from JECRC University, Jaipur, Rajasthan, India in Display Electronics devices. Currently, she is an Assistant Professor in the ECE department of JECRC University. Her research interests are in the area of nanomaterials, display devices, and VLSI design. She has published over 24 peer-reviewed papers in SCI, prestigious journals and peer-reviewed conference proceedings.

Himani Bali completed her B.Tech. and M.Tech. in Electronics and Communication from Lovely Professional University, Phagwara, India in 2012. She completed her Ph.D. in Mobile Adhoc in Networks 2019. She has 8 years of teaching experience and is working as an Assistant Professor in the Department of Electronics and Communication, JECRC University, Jaipur, since 2012. Her main research work focuses on wireless communication, mobile adhoc networks, artificial intelligence.

Anju Kalwar was born in Kota, Rajasthan, India. She received the B.C.A and the M.Sc. degrees from University of Rajasthan Vidhayapeth, India and the Ph.D. degree from JECRC University, Jaipur, India. She has 7 research papers in prestigious journals and peer-reviewed conference proceedings.