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Impact Of Distributed Generation On The Economy Of Electrical Power System: A Cost Analysis Perspective

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Abstract: Distributed Generation Systems (DGS) represent an energy source for local loads to transmit voltage from a local generating plant, utilizing a diverse array of small-scale energy sources to meet electricity demands. While numerous studies focus on enhancing voltage profiles and stability within transmission and distribution networks through Distributed Generation (DG), economic considerations remain relatively unexplored. This work addresses the gap by examining the economic parameters associated with integrating Photovoltaic Distributed Generation (PV DGS) into power systems, utilizing a WSCC 9-bus system, modified to an 11-bus configuration by connecting two PV DGS to the load buses. By assessing the initial infrastructure cost, payback period, and return on investment, this study offers insights into the economic implications of incorporating PV DGS, contributing to a deeper understanding of the interplay between technical and economic factors in distributed energy systems.

***Index Terms* -** Western system coordinating council, Distributed generation, Photovoltaic, Initial investment cost, payback period, Return on investment.

I. Introduction

The modern energy landscape is witnessing a paradigm shift from centralized power generation to decentralized systems, largely driven by the integration of Distributed Generation Systems (DGS) [1]. Unlike traditional approaches reliant on large central power plants, DGS utilize an array of small-scale energy sources to meet electricity demands. This transformation not only promises enhanced reliability and resilience but also opens avenues for improved economic viability. [2]

While numerous studies have delved into the technical aspects of integrating DGS into existing power grids [3], thereremains a notable gap in analysing the economic implications of such integration. Understanding the economic feasibility of distributed generation (DG), particularly in terms of initial infrastructure cost, payback period and return on investment (RIO), is essential for informed decision making in energy planning and management.

To address this gap, this study focuses on incorporating Photovoltaic (PV) DGS into a representative power system, using the modified WSCC 9 bus system as a case study. By expanding the WSCC 9 bus system to an 11 bus system and integrating PV DGS at load buses, this work helps in investigating the economic dynamics of such integration. Specifically, our analysis seeks to elucidate how the incorporation of PV DGS influences the economy of the power system, shedding light on crucial parameters like initial infrastructure costs, payback periods, and ROI.

Through this endeavour, the work provides valuable insights into the economic viability of integrating PV DGS into power systems, thereby facilitating informed decision-making processes for stakeholders in the energy sector. Ultimately, our study aims to contribute to the ongoing discourse on sustainable energy transitions by bridging the gap between technical analyses and economic considerations in the context of distributed generation.

The objective of this work, are to analyse and understand the load flow parameters of WSCC 9 bus system, if the load flow parameters are stable and satisfying than system is modified. To modify the WSCC 9 bus system to 11 bus system for placing the PV distributed generation and calculate the initial investment cost of PV DG system placed at load buses. Also evaluate the payback period of initial investment and return on investment of the equipment installed in the distribution plant.

II. Power system Modelling

A. WSCC 9 Bus System

In the present work, WSCC is made up of nine buses connected by transmission lines, The system has several components such as generators, loads, transformers etc. The transmission line length can be calculated as :

$$L_{length} = \frac{\sqrt{X*B}}{2*Pi*f} * C \tag{1}$$

Where,

B = Susceptance, X = Reactance, C = Velocity of light, f = Frequency. The equations used to calculate susceptance, reactance, and resistance are given below:

$$R_{actual} = R_{base} * R_{pu} \tag{2}$$

$$R\left(\frac{Ohm}{Km}\right) = \frac{R_{actual}}{L_{length}} \tag{3}$$

$$X_{actual} = X_{base} * X_{pu} \tag{4}$$

$$L_{actual} = \frac{X_{actual}}{2} * Pi * f \tag{5}$$

$$L\left(\frac{H}{Km}\right) = \frac{L_{actual}}{L_{length}} \tag{6}$$

$$B_{actual} = B_{base} * B_{pu} \tag{7}$$

$$C\left(\frac{F}{Km}\right) = \frac{C_{actual}}{L_{length}} \tag{8}$$

By Using these equations reactance, resistance, capacitance and transmission line lengths are calculated and used in the Matlab-Simulink model to build the WSCC 9 bus system as shown the figure 1.

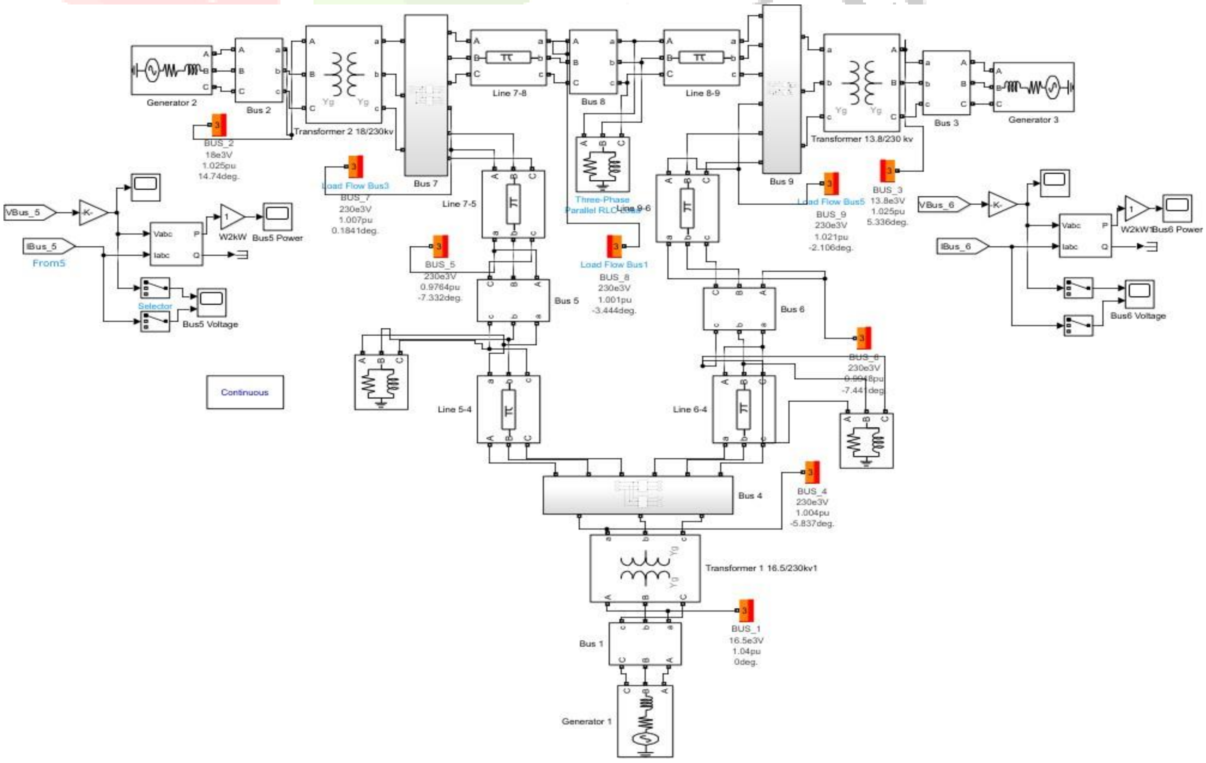

Fig 1. Simulink Model of WSCC 9 Bus system (Base System)

A Photovoltaic DG that is located closer to the load centers is connected to the WSCC 9 bus system. and the distributed generations are connected to the loads by two external buses, designated 10 and 11. and increased loads at load centers will be supplied by these photovoltaic DG; this configuration is referred as the modified WSCC 11 bus system as shown in figure 2.

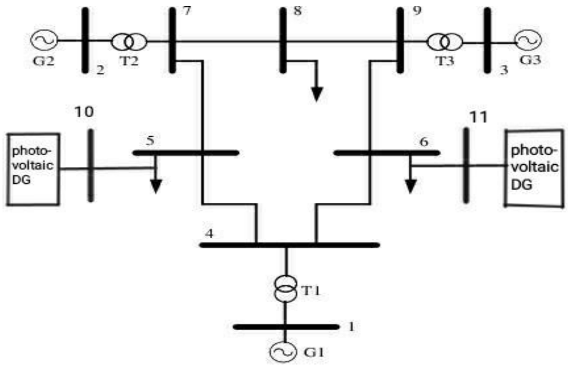

Fig 2 Modified WSCC 11 Bus system

B. *Photovoltaic Distributed generation*

A photovoltaic array is a collection or configuration of several connected solar panels or modules. The purpose of these arrays is to use the photovoltaic effect to turn sun light into power. [5] A key element of solar power systems, photovoltaic arrays are used in a variety of settings, from large-scale solar farms to residential rooftops. These are the key components that are utilized to model a 250 KW grid connected photovoltaic DG. [6]

1. PV Array :

A group of solar cells that have been connected and enclosed to produce power is referred to as a module. A solar panel is constructed using these modules. The equations define the diode I-V characteristics for a single module.

$$I_d = I_0\left[\exp\left(\frac{V_d}{V_T}\right) - 1\right] \tag{9}$$

$$V_T = \frac{kT}{q} \times nI \times N_{\text{cell}} \tag{10}$$

I_d represents the diode current, I_0 is the reverse saturation current of the diode, V_d is the voltage across the diode, V_T is the thermal voltage of the diode, T is the temperature in Kelvin. q is the elementary charge. n_I is the ideal factor of the diode and Ncell is the number of solar cells in the module. [7] there are 86 parallel strings in the PV array. Seven 415W modules are connected in series to form each string.

2. Three phase DC/AC Converter :

A three-level IGBT bridge PWM-controlled model is used to represent the converter. The harmonics produced by the IGBT bridge are filtered using the inverter choke RL and a tiny harmonics filter C. There – Phase Inverter equations are :

$$\frac{V_{DC}}{2}(S_{11} + S_{21} + S_{31} - S_{12} - S_{22} - S_{32}) = V_{an} + V_{bn} + V_{cn} + 3V_{no} \tag{11}$$

$$\frac{V_{DC}}{6}(2S_{11} + 2S_{21} + 2S_{31} - 3) = V_{no} \tag{12}$$

$$\frac{V_{DC}}{3}(2S_{11} - S_{21} - S_{31}) = V_{an} \tag{13}$$

$$\frac{V_{DC}}{3}(2S_{21} - S_{21} - S_{31}) = V_{bn} \tag{14}$$

$$\frac{V_{DC}}{3}(2S_{31} - S_{21} - S_{11}) = V_{cn} \tag{15}$$

3. Inverter Control

a) MPPT Controller : The 'Perturb and Observe' method is the foundation of the Maximum Power Point Tracking (MPPT) controller. The MPPT technology automatically modifies the inverter VDC regulator's VDC reference signal to achieve a DC voltage that optimizes the PV array's power output. Equation (Perturb and Observe):

$$V_{new} = V_{old} \pm \delta V \tag{16}$$

b) VDC Regulator :It finds the present regulator's necessary Id (active current) reference.

c)Current Regulator: The regulator calculates the necessary reference voltages for the inverter based on the current references Id and Iq (reactive current). The Iq reference in our case is set to zero.

d) PLL and Measurements: Needed for voltage/current measurements as well as synchronization.

e) PWM Generator: It is utilizing the necessary reference voltages as a basis, generate firing signals for the IGBTs. PWM generation is the process of creating pulses with a predetermined duty cycle by using the carrier frequency and reference voltages.

$$D = \frac{V_{\text{ref}}}{V_{\text{max}}} \tag{17}$$

Where,

D is the duty cycle, Vref is the reference voltage, and Vmax is the maximum voltage.

The figure 3 shows a Simulink model of a photovoltaic DG system. It has a load of 250K watts, is connected to a grid, and has a bus voltage of 25K volts.

Since the WSCC system has a voltage of 230 KV and the PV system has a voltage of 25 KV, a step-up transformer is installed to connect the two systems. This connection must meet three requirements. identical phase sequence, frequency, and voltage levels.

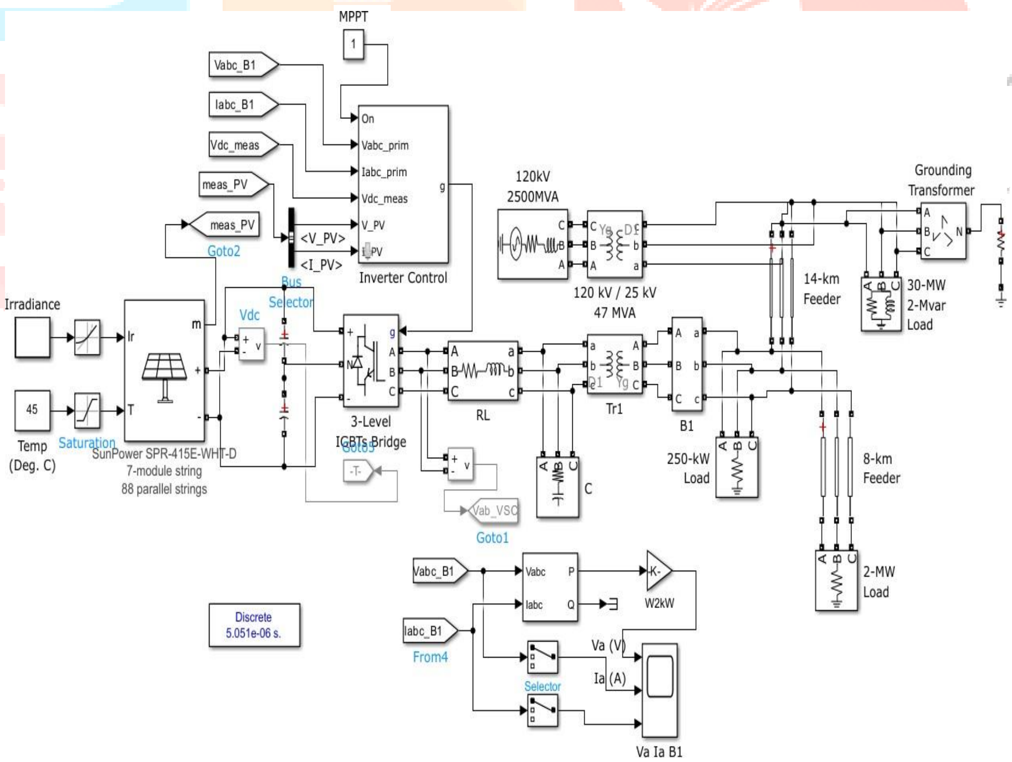

Fig. 3 Simulink model of grid connected PV DG system

III. COST ANALYSIS

1) Initial Investment Cost : Calculating the initial investment cost is crucial to assess the financial feasibility of integrating PV DG into the power system. It helps in understanding the capital required for equipment procurement, installation, and infrastructure upgrades, providing insights into the economic viability of the project.

2) Payback Period : Calculating the payback period is essential to determine how long it takes for the initial investment in PV DG to be recovered through energy savings and generation. It provides valuable insights into the financial sustainability of the project, guiding stakeholders on the timeline for realizing returns on their investment in distributed generation infrastructure. [8]

The formula to calculate the payback period is:

$$Initial\ Investment\ Cost\ = \frac{Cost\ of\ investment}{Average\ annual\ cash\ flow} \tag{18}$$

In order to determine the average yearly cash flow considering the fixed cost is 110 rupees, the electricity cost is 4.75 rupees, the meter cost is 1.56 rupees based on consumption*, and the total cost includes 9% GST.

3) Return on investment :

To evaluate the financial viability of incorporating PV DG into the power grid, the return on investment (ROI) mustbe calculated. By weighing the returns on investment against the initial cost, it calculates the efficiency of the investment and helps with resource allocation and future prospective investments in distributed generating infrastructure. The returnon investment is calculated for three years. The formula to calculate return on investment is :

$$Return\ on\ investment\ = \frac{Current\ cost\ of\ investment - Cost\ of\ investment}{Cost\ of\ investment} \tag{19}$$

IV. RESULTS AND DISCUSSION

I. TABLE I

WSCC 9 BUS SYTEM LOAD FLOW ANALYSIS:

Sl no	**Block Name**	**Vbase (KV)**	**P (MW)**	**Q (MVA)**
1	Generator 2	18.0000	163.0000	28.0952
2	load 1	230.0000	100.1559	35.0546
3	Generator 3	13.8000	85.0000	5.7830
4	Bus no 3	230.0000	0.0000	0.0000
5	load 2	230.0000	119.1807	47.6723
6	Bus no 5	230.0000	0.0000	0.0000
7	load 3	230.0000	89.0584	29.6861
8	Bus no 7	230.0000	0.0000	0.0000
9	Generator 1	16.50000	67.0964	25.2404

We can observe from the above WSCC 9 bus load flow analysis table, 3 loads i.e 100 MW, 119.1807 MW and 89.0584 MW is supplied by the 3 generators.

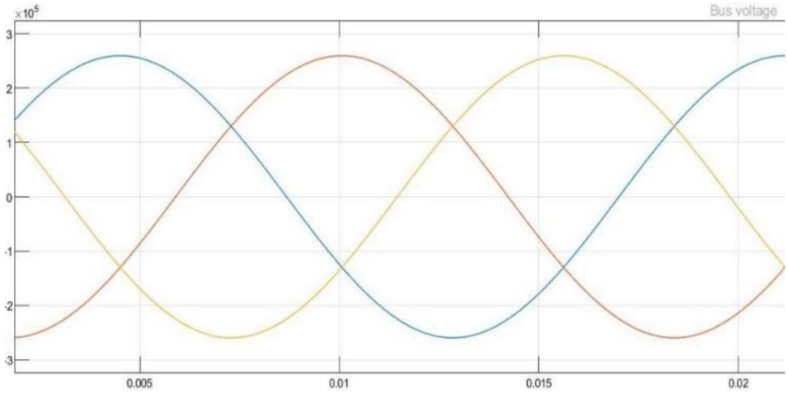

Fig 4. Bus voltage of WSCC 9 Bus system

The WSCC 9 Bus system Bus voltage i.e 230 KV is plotted in the above figure 4.

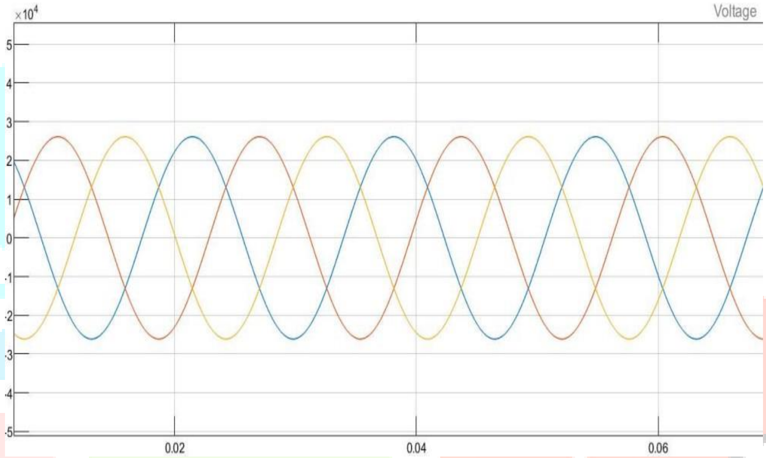

Fig. 5. Grid connected PV DG Voltage

Figure 5 shows the 25 KV grid voltage of a photovoltaic DG. From both figure 4 and 5 there is a voltage difference so to connect WSCC with PV system a transformer is used.

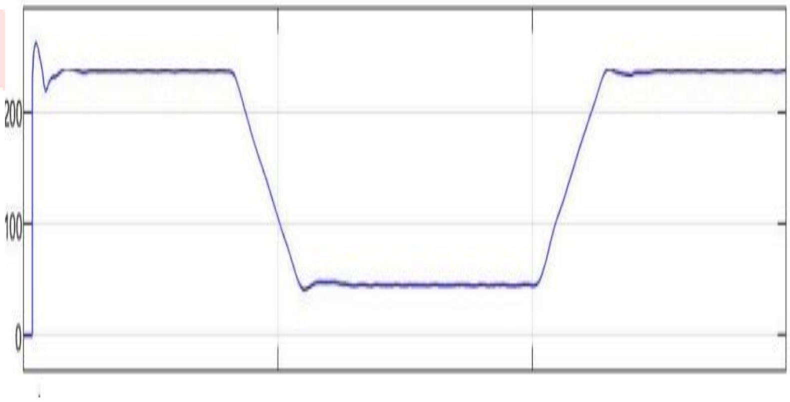

Fig 6. Grid connected PV DG Power

above figure shows the 250 KW power of the PV (DG) supplying to a grid connected load. When the WSCC system is updated, i.e. connected to photovoltaic distributed generation, a load change at Buses 5 and 6 is taken into consideration. The increased load changes are 50KW, 100KW and 150KW.

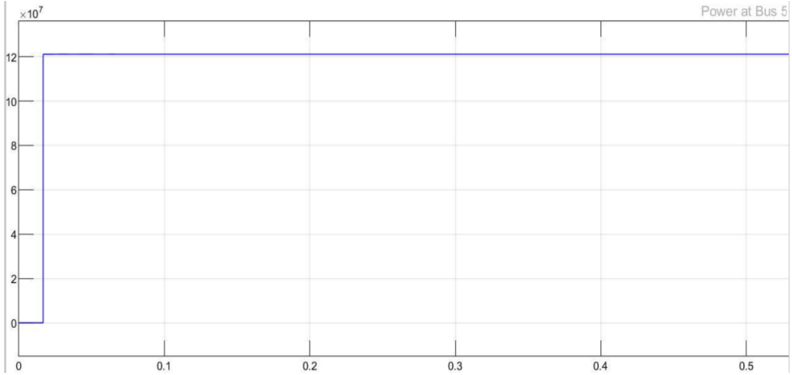

Fig 7. Increased load of 150KW at bus no 5 output power

The power flow in bus number five is 119.1807 MW as shown in the 9 bus load flow analysis table. Considering a increase in load of 150kw at bus no 5, it is supplied by the photovoltaic DG, we can observe in figure no 7 that the power output wave form slightly increase but remains stable. similarly for bus no 6 and 8 are also showing the stable conditions. Based on this, we can conclude that the systemis stable when an increased load is supplied by PV and that it is also possible to implement this system in practice.

A. Initial Investment Cost of 50KW PV DG

II. TABLE
INVESTMENT COST OF 50KW PV

SL No	Components	Cost /Unit (INR)	Quantity	Total Cost (INR)
1	Solar Panels (415 W)	34/W	121	17,07,310
2	Mounting Framework	7650/KW	25	3,82,500
3	Inverter	50,000/KW	10	5,00,000
4	Wires	2,000/KW	50	1,00,000
5	Battery (120/200Ah)	12,000	25	3,00,000
6	Combiner Box	10,000/KW	10	1,00,000
7	Primary Junction Box	8,000	5	40,000
8	Fuses & Disconnects	3,000	set	15,000
9	safeguard switch	500	19	9,500
10	Energy-monitoring gauge	4,000	1	4,000
11	Remote Supervision & Management	2,00,000	1	20,000
12	Transformer	10,00,000	1	10,00,000
	Total			43,58,310
13	VAT	5.5%		2,39,707.05
14	Shipping and setup	10%		4,35,831
15	Miscellaneous	6%		2,61,498.6
16	Project Management & Design engineering	10%		4,35,831
	Total Cost			**57,31,177.65**

Similar calculations are made for the initial investment expenses for increased loads of 100KW and 150KW.

III. Table
PAY BACK PERIOD OF PV

SL No	Increased load (KW)	Initial investment cost (INR)	Pay back period (years)
1	50	57,31,177.65	1.89
2	100	1,04,38,470	1.72
3	150	1,44,15,030	1.58

From the above table we can observe that as the load is increasing the initial investment cost is also increasing with increase in pay back period.

IV. TABLE
RETURN ON INVESTMENT

SL No	Increased load (KW)	Return on investment in Percentage
1	50	59.21
2	100	74.83
3	150	89.90

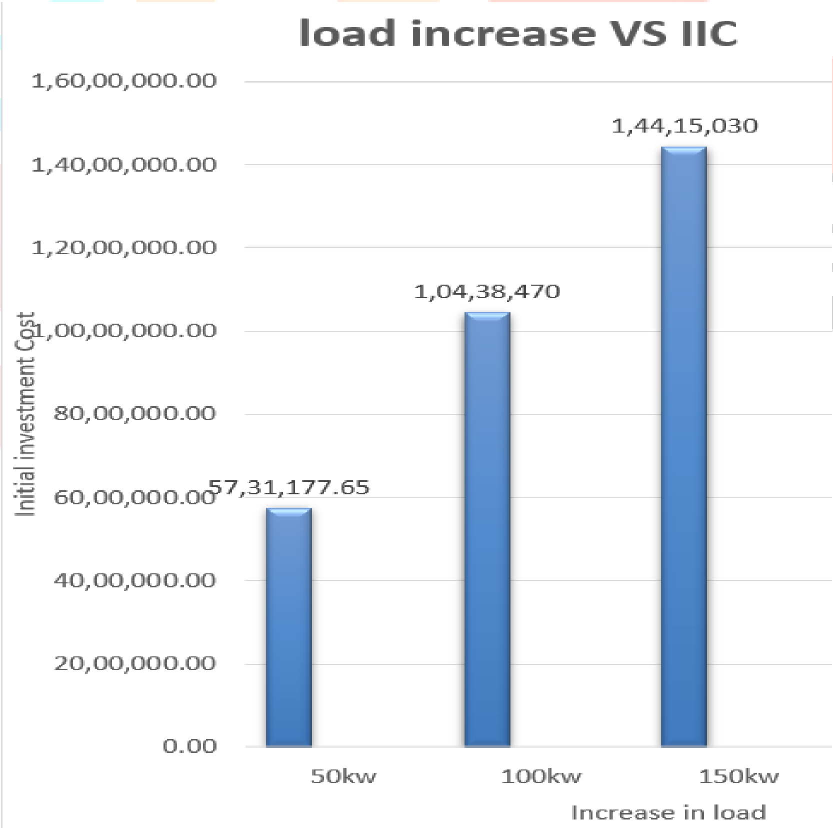

Fig. 8. Increase in load VS Initial investment cost

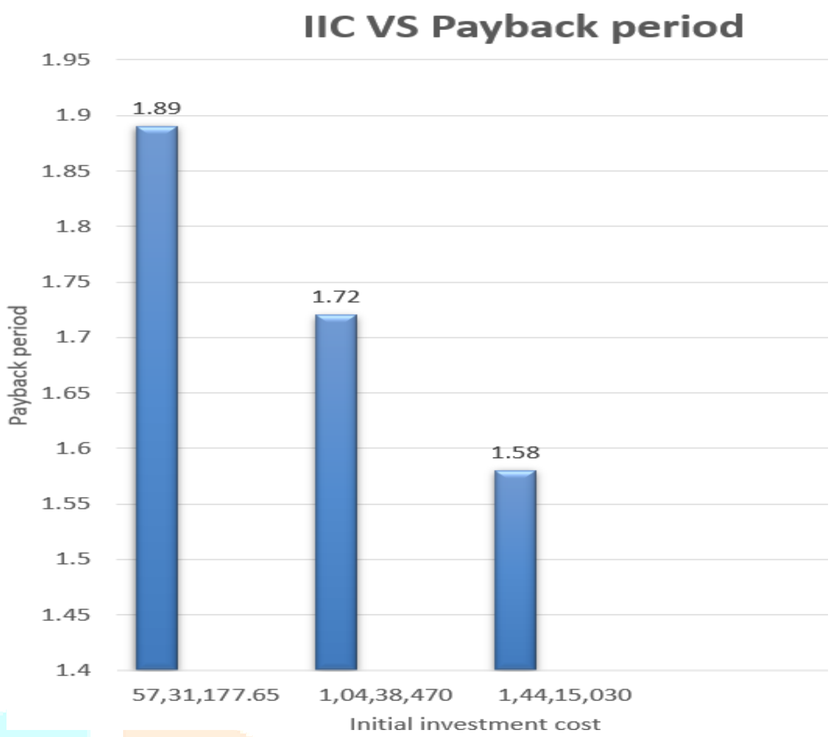

Fig. 9. Initial investment cost VS Payback period

From the above graphs, we can observe that the payback period will shorten as the investment cost increases, and also as the load is increasing the percentage of return on investmentis also increasing, which aids in helping the decision makers with investment decisions.

This cost analysis study also allows us to determine that there is a reduction in transmission losses and Distribution Losses. The requirement for substantial transmission and distribution infrastructure is decreased by distributed generation. Power can be produced closer to the point of consumption, resulting in reduced energy travel distances and a reductionin transmission losses across vast distances. Both consumers and utilities can save money with this. In addition of dis- tributed generation to the power system adds redundancy and resilience. Distributed generation systems can continue to supply electricity to limited areas if centralized power sources face interruptions or outages. This increased dependabilityreduces downtime and economic costs associated with power outages, which benefits businesses and customers who relyon continuous power delivery. Distributed generation systems,particularly those that incorporate energy storage or smartmanagement systems like photovoltaic array, can assist inreducing peak demand on the grid. These systems alleviate grid pressure by supplying power during peak hours or storingextra energy for later use, potentially reducing the need for expensive peak power production facilities. This can save money by not investing in new infrastructure just for peak demand periods. Furthermore distributed generation contributes to the democratization of energy production. It empowers individuals and communities to become energy producers, allowing them to generate their electricity and, in some cases, sell excess power back to the grid. [5] This involvement in energy production fosters a sense of ownership.

CONCLUSION : The main goal of this study is to understand the photovoltaic DG integration with WSCC system and perform the economy analysis of increased load in the WSCC system. To study the stability and know the voltage profiles and know the power rating for the above system, the WSCC systemis modelled and load flow analysis is performed for the base case system. After confirming the stable conditions, PV DGis integrated with the WSCC modified system. Furthermore economic analysis is performed and results are presented in this work. For the above system, 50kw increase in load requires the investment cost of 57,31,117.65 (INR), with payback period of 1.89 years. and similarly for 100kw and 150kw load increased costs and payback period calculatedand presented. By observing these we can say that as theinitial investment cost increases and increase in the load the payback period is decreased with percentage increase in return on investment. These costs will assist decision makers while investing.

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