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DEVELOPMENT OF ECONOMIC PROCESSES UTILIZING SOLAR ENERGY

Анотація. *У статті розглядається проблема електропостачальних компаній щодо встановлення пріоритету жорсткого контролю за продуктивністю системи, оскільки це надзвичайно допомагає економно планувати витрати на технічне обслуговування з повним задоволенням очікувань клієнтів. Метою дослідження є проведення порівняльного аналізу продуктивності мікромережі з продуктивністю об'єднаної мікромережі та національної електромережі. Досліджено мікромережу, яка використовує сонячну енергію в розріджених місцях на горбистій місцевості для забезпечення надійного електропостачання промислових будинків, які займаються процесами виробництва продукції. Ці виробничі процеси, як частина малих і середніх галузей промисловості, впроваджують товари та послуги, необхідні для забезпечення економічного зростання та розвитку в країні, де мережеве електропостачання зазнає частих погодних умов і, отже, є дуже дорогим з точки зору існування, а також обслуговування. Тенденція використання сонячної енергії дала простір для самозабезпечення та кращих засобів до існування для людей, які живуть далеко від міст, але продукти, які вони виробляють, можуть відправлятися для споживання в сусідні міста. Таким чином, все більша залежність від сонячної енергії призводить до політики економічного зростання країни. Крім того, це сприяє безперебійному та якісному електропостачанню з використанням чистої енергії замість виробництва електроенергії на основі викопного палива для захисту навколишнього середовища, що зменшує викиди парникових газів та відповідно ризики для здоров'я. За допомогою методів перевірки надійності продуктивність сонячної електростанції кількісно оцінюється та порівнюється з продуктивністю національної мережі, що постачає електроенергію віддаленому населенню. Покращена енергетична безпека, легкий доступ і оперативні реакції сонячної електростанції як заміни електромережі допомагають розвивати економічне зростання країни.*

Ключові слова*: сонячна енергія, мікромережа, потужність, показники надійності, втрата навантаження, ризик.*

JEL Classification: O18, L94, Q41

Absztrakt. *A cikk azt vizsgálja, hogy az áramszolgáltató cégek számára milyen problémát jelent a rendszerteljesítmény szigorú ellenőrzésének előtérbe helyezése, mivel ez nagyban segíti a karbantartási költségek gazdaságos tervezését a vevői elvárások egyidejű kielégítésével. A tanulmány célja a mikrohálózat teljesítményének összehasonlító elemzése az egységes mikrohálózattal, valamint az országos villamosenergia-hálózat teljesítményével. Olyan mikrohálózatot vizsgáltunk, mely dombos területen elhelyezkedő napenergiát használ a termékgyártási folyamatokkal foglalkozó ipari épületek megbízható áramellátásához. Ezek a termelési folyamatok mint a kis- és közepesnagyságú ipar részeként olyan árukat és szolgáltatásokat vezetnek be, amelyek egy országban a gazdasági növekedés és fejlődés biztosításához szükségesek, és ahol a hálózati energiaellátás időjárási viszonyoknak van kitéve, s ezért nagyon költséges a fenntartás és a karbantartás szempontjából. A napenergia felhasználásának trendje teret adott a városoktól távol élő emberek önellátásához és jobb megélhetéséhez, de az általuk előállított termékek a környező városok fogyasztóihoz is kerülhetnek. Így a napenergiától való növekvő függőség az ország gazdasági növekedési politikájához vezet. Emellett a fosszilis tüzelőanyag alapú villamosenergia-termelés helyett tiszta energiát használó, zavartalan és jó* *minőségű villamosenergia-ellátást segít elő a környezetvédelem érdekében, ami csökkenti az üvegházhatású gázok kibocsátását és ennek megfelelően az egészségügyi kockázatokat is. Megbízhatósági vizsgálati módszerek segítségével egy naperőmű teljesítményét számszerűsítik és összehasonlítják a távolabban élő lakosságot ellátó országos villamoshálózat teljesítményével. A jobb energiabiztonság, a könnyű hozzáférés és a napenergia rugalmassága, mint a központi hálózati rendszer helyettesítője, elősegíti az ország gazdasági növekedését.*

Kulcsszavak: *napenergia, mikrohálózat, teljesítmény, megbízhatósági mutatók, terhelési veszteség, kockázat.*

Abstract. *The concern of the electric utility companies to prioritize tight control on system performance is addressed in the paper as it immensely helps planning maintenance expenditure economically with customers' expectations fully met. . The paper aims at making a comparative study of performance of the micro-grid power system with that of the interconnected micro-grid and national grid. A micro-grid that utilizes solar energy in sparse locations in hilly terrain for ensuring reliable electric supply to industrial houses engaged in product manufacturing processes has been considered. These manufacturing processes as a part of small and medium industries introduce goods and services necessary for securing economic growth and development in the country side where grid power supply is subject to frequent weather disturbances, and hence, very costly from the perspective of sustenance as well as maintenance. The solar energy trend has given scope for self-reliance and better livelihood of people who live away from cities but the products what they manufacture may be sent for consumption in the nearby cities. Thus, more and more dependence on the solar energy leads to nation's economic growth policy. Moreover, it adds to uninterrupted and quality electric supply using clean energy in place of fossil fuels-based generation of electricity to protect environment; allows reducing health hazards and mitigating greenhouse gas emissions. Using reliability techniques, solar energy plant performance is quantitatively judged and compared with respect to the performance of the national grid supplying power supply to the remotely located population. The improved energy security, easy access and operational responses of the solar plant as a substitute to the grid power supply help develop economic growth of a nation.*

Keywords*: Solar energy, Micro-grid, Capacity, Reliability indices, Loss of load, Risk.*

Introduction. A micro-grid is a small network of electricity users in a local area consisting of low voltage power generating units, storage devices and multiple loads but usually connected to the larger regional or national grid. The simplified layout makes micro-grids not only reliable but an economic viability with the continuously falling price of solar panels, battery storage and other peripherals. Further, micro-grids are particularly suited to remain uninterrupted against natural disaster and calamity in its vicinity. Whereas the regional / national grid fails to provide continuity of electric supply with quality voltage and frequency to many pockets following emergency/disturbances owing to adversities, the micro-grids serve the local area (s) independently and smartly without the help of the centralized regional/national grid. It is the quality that micro-grids are now considered as the potential source of clean energy with higher reliability.

Literature review. In recent years thrust on renewable energy related research is given due coverage in various publications around the world. One such remarkable study by Rafindadi and Ozturk (2017) has investigated the impact of renewable energy on the economic growth prospect of Germany to show that a 1% increase in renewable energy consumption in Germany boosts German economic growth by 0.2194%. IRENA in its report (2016) "Renewable Energy Benefits: Measuring the Economics" provides the first quantification of the macroeconomic impact of doubling the global share of renewable in the energy mix by 2030. In addition, it explains that accelerating the deployment of renewable energy will fuel economic growth, create new employment opportunities, enhance human welfare, and contribute to a climate-safe future.

While linking renewable energy (RE) to rural development in the OECD report (2011) it is observed that renewable energy (RE) electricity sector grew by 26 % between 2005 and 2010 globally and currently provides about 20 % of the world's total power (including hydro power). Interestingly rural areas attract a large part of investment related to RE deployment, tending to be sparsely populated but with abundant sources of RE. The case studies found that RE deployment provides local communities with some benefits, including:

- New revenue sources providing extra income for landowners. Farmers and land owners who integrate RE production into their activities can diversify and increase their income sources.
- New job and business opportunities for youths in the region. RE can create direct jobs such as operation and maintenance of equipment whereas long-term jobs are indirect (arising out of renewable energy supply-chain: manufacturing and specialized services).
- Innovations in products, practices and policies in rural areas. In hosting RE, rural areas are the places where new technologies are tested. Small and medium-sized enterprises provide new business opportunities. Any import of technology is suitably modified adapting to local needs and conditions.
- Capacity building and community empowerment. As villagers acquire skills in the RE electric industry, they explore new opportunities for investment to deal with RE deployment as per the policy norms.
- Affordable energy. RE provides remote rural regions with the opportunity to produce their own electric power to fulfill the local demand. The dependence on the national / regional grid may be dispensed with to be self-sufficient and being able to generate reliable and cheap energy leading to rapid economic development.

A few publications by Kim (2008), Billinton and Allan (1996), Billinton et al (1981) and Llria et al (2011) have gone in the deeper insight in the Indian context to study the performance of a solar powered micro-grid with and without the main grid in the recent time by Gupta and Kumar (2021) and Kumar (2022). The results of the investigation are very encouraging.

Purpose of the study. This paper aims at making a comparative study of performance of the micro-grid power system with that of the interconnected micro-grid and national grid.

Research results.

1. Micro-grid Model Representation

A micro-grid is capable of supplying electrical power to small communities with population ranging up to 500 households with overall energy demands ranging up to several thousand KWh per day. Microgrids normally support low voltage networks and powered by steadily falling costs for solar, wind or biomass power generation. The developers are also happy to find plenty of options than diesel generators as back-up power to the remotely located power system. Although distributed generation (DG) concept is expensive over traditional generation; however, a continuously falling cost of renewable energy has opened up a new source of power from micro-grids. While these smaller electricity networks are required to meet only limited electricity, they are demonstrating a way to bring green energy to the remote and distributed locations where relatively lesser population exists (Gupta and Kumar, 2021). Distributed Generation (DG) systems can employ numerous, but smaller plants, which can provide power on-site with very little dependence on the distribution and transmission grid. Figure 1 represents a simple schematic diagram of the layout (Kumar, 2022).

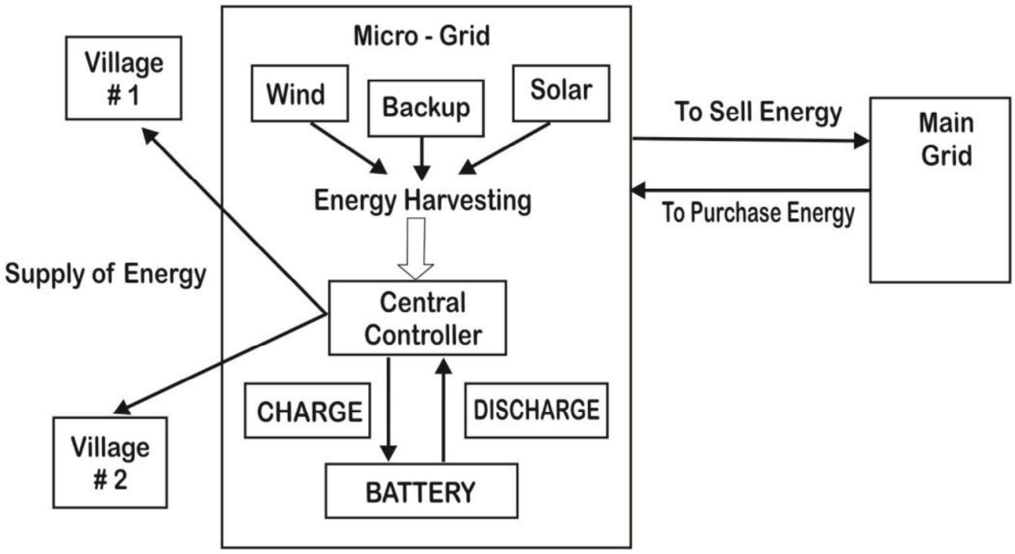

Figure 1. Localized micro-grid supply distribution – schematic diagram

To maximize availability of localized generation and efficiently distribute power to a larger area, micro-grids offer a viable solution during sudden power outages. A micro-grid is capable of isolating itself via a utility branch circuit in co-ordination with standby generators in the area, thereby helping each building operation independent of the grid supply. Kumar (2022) has discussed in detail how a micro-grid utilizes solar energy for reliable power supply to industrial houses engaged in product manufacturing processes in remote and sparse locations. A micro-grid can sense load perturbations and fault conditions, and redistribute power to as many critical areas as possible under any given situation. The significant advantages what micro-grids offer are:

- Local electricity generation.
- Local load management.
- Ability to automatically decouple from the grid and go into “island mode”.
- Ability to work cohesively with the local utility as well as the main grid.

A problem is faced as to what is to be done in case of supply outage due to unforeseen reasons. Thus, the emerging scenario demands for practical and economical solutions to serve the consumers with the continuity and quality of energy supply under the sudden outage condition that the micro-grid is likely to face. Two solutions to this problem are described as: (i) the area load is transferred to the main grid; (ii) the area load is served by the standby generators such as diesel generator, biomass generation, mini or micro hydro generating units, etc.

2. Micro-grid Connected with Main Grid (Standby)

A standby model refers to the case in which a key element (or unit) has a backup element (or unit) in an "off" state until needed. When the key element fails, a sensing-cum-switching (SS) device monitors the operating unit failure and turns on the "standby" (backup) element or unit so that the system continues to operate without interruption. Figure 2 shows the main grid as the backup unit. A relatively higher degree of reliability of SS also matters a lot in making the system reliable. The mission over here lies in the fact that the key element and the standby unit together contribute to system success during the entire mission time 0-t.

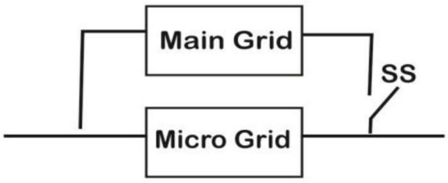

Figure 2: Micro-grid with main grid as standby

3. Performance Assessment Methods

[A] Reliability of Standby System

$$R_{SB} = e^{-\lambda_1 t} + \frac{\lambda_1}{\lambda_2 - \lambda_1}\left[e^{-\lambda_1 t} - e^{-\lambda_2 t} \right] \quad \ldots\ldots \quad (1)$$

where λ_1 and λ_2 are the failure rates of micro-grid and main grid respectively; and t is the mission time.

[B] Supply System Performance Indices

The following reliability indices are used as measure of supply system performance indices:

SAIFI = System Average Interruption Frequency Index

$$= \frac{\text{Total number of facility interruptions}}{\text{Total number of facilities served}} \quad \ldots\ldots \quad (2)$$

SAIDI = System Average Interruption Duration Index

$$= \frac{\text{Total number of facility interruption durations}}{\text{Total number of facilities served}} \quad \ldots\ldots \quad (3)$$

ASAI = Average System Availability Index

$$= \frac{\text{Total available service hours}}{\text{Total service hours demanded}} \quad \ldots\ldots \quad (4)$$

[B] Load Point / Customer Service Performance Indices

The following reliability indices are used as measure of customer service indices:

$$\textbf{CAIFI} = \text{Customer Average Interruption Frequency Index} = \frac{\text{Total number of customer interruptions}}{\text{Total number of customers affected}} \quad \ldots.. \quad (5)$$

$$\textbf{CAIDI} = \text{Customer Average Interruption Duration Index} = \frac{\text{Total number of customer interruption durations}}{\text{Total number of customers interruptions}} \quad \ldots.. \quad (6)$$

4. Case Study Results

A case study was formulated based on Figure 3 representing the micro-grid inter-connection with the main grid (Kumar, 2022; Sarkar, Kumar and Bhaduri, 1991).

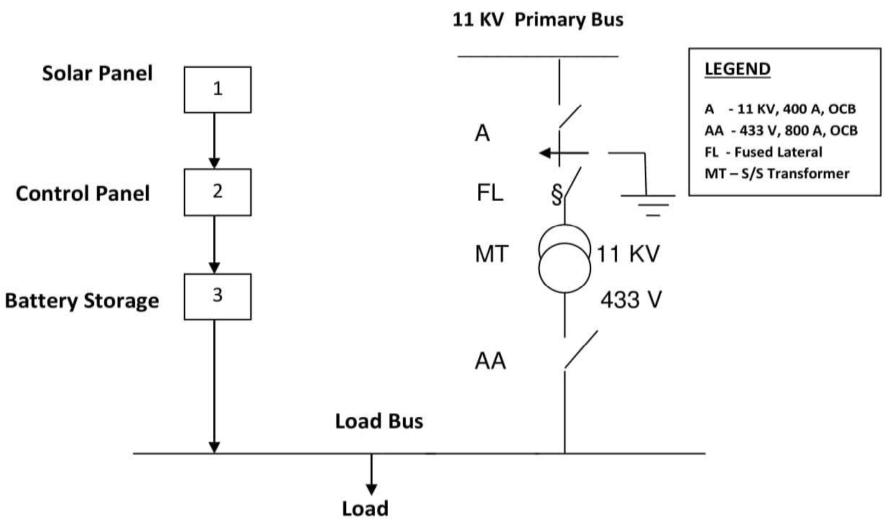

Figure 3. The micro-grid system in operation with the main grid

The field data concerning the failure/outage frequency as well as the failure/outage time duration on daily basis for the system reliability study was obtained and presented in Table 1. The performance comparison of micro-grid using solar plant (stand alone system) is done with the interconnected micro-grid and main grid system; and the results are tabulated in Tables 2 and 3, the discussion of which is done with the help of Figures 4 to 8. The total number of facilities being served is 400, and the total number of customer interruptions of the tune of 218 on a day.

Table 1. The basic data for system reliability study of Figure 3

System	Combined Breakdown and Maintenance			Customers	
	λ_e (f/day)	r_e (hr)	$\lambda_e\ r_e$ (f-hr/day)	Vill #1	Vill #2
Solar Plant	**0.03024**	**0.0069**	**0.00021**	**200**	**200**
Solar plant + Main Grid	**0.02208**	**0.0021**	**0.000046**	**200**	**200**

[A] R_{SB} = 0.99967 (both solar and main grid together) ….. (7)

[B] Supply System Performance Indices

A comparison of the system load bus performance indices is made in Table 2.

Table 2. Comparison of system performance / service indices

Figure / Scheme	SAIFI (interruptions / day)	SAIDI (hours)	ASAI (per unit)
Micro-grid	**0.03024**	**0.0069**	**0.99979**
Micro-grid + Main grid	**0.02208**	**0.0021**	**0.99995**

[B] Load Point / Customer Service Performance Indices

These indices are measures of customers' satisfaction. Assume the total number of customers affected to be 218 out of total customers of 400. A comparison of the customer performance indices is made in Table 3.

Table 3. Comparison of customer service indices

Figure / Scheme	CAIFI (interruptions / day)	CAIDI (hours)	ASAI (per unit)
Micro-grid [MIC]	**0.0555**	**0.0127**	**0.99979**
Micro-grid + Main Grid [MIC + MG]	**0.0405**	**0.0039**	**0.99995**

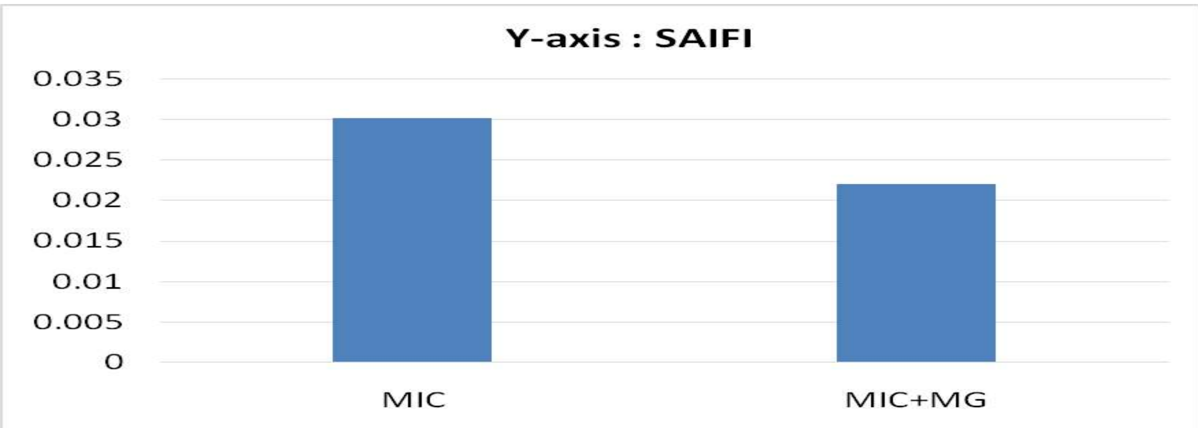

Figure 4. Response of SAIFI, interruptions per customer served

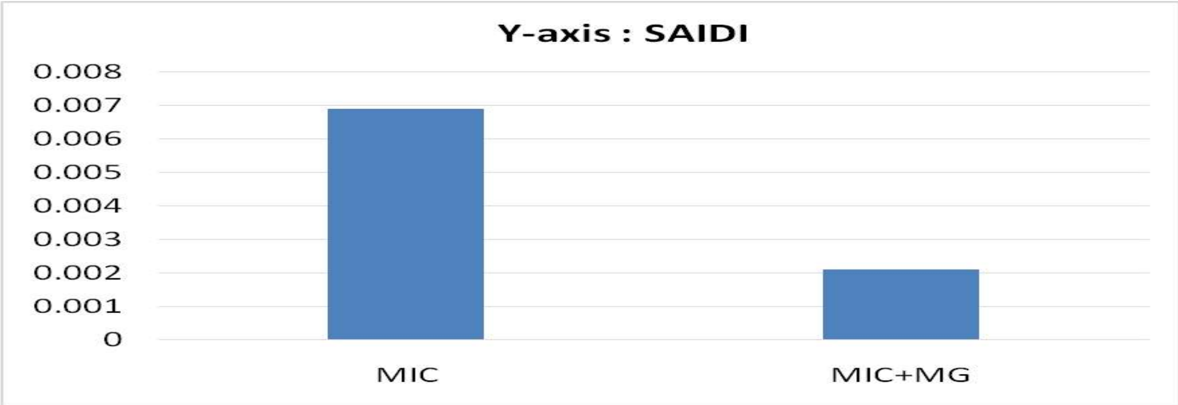

Figure 5. Response of SAIDI in hours per customer served

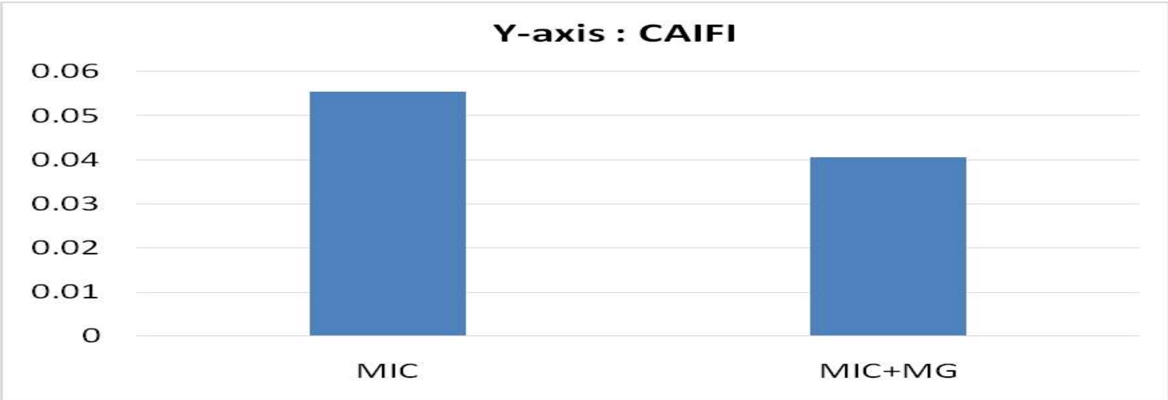

Figure 6. Response of CAIFI, interruptions per customer affected

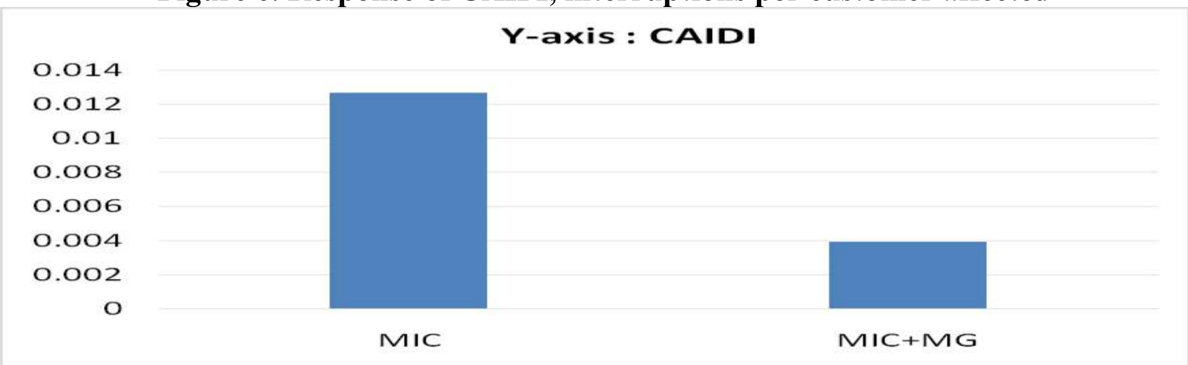

Figure 7. Response of CAIDI in hours per customer interruption

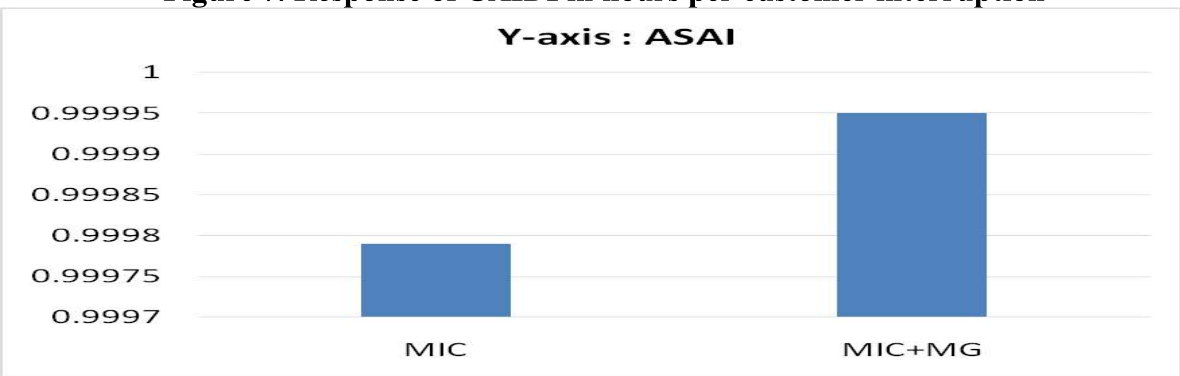

Figure 8. Response of ASAI in percentage

Figure 4. In Figure 4, the bar diagram depicts system average interruption frequency per day in two different conditions. The interruptions are shown on Y-axis over the one-day period which is taken along the X-axis. The lowest value is seen in

case of joint micro-grid and main grid operation when compared with the micro-grid functioning alone.

Figure 5. Figure 5 is the bar diagram which indicates system average interruption duration in hours per year. Over here, the Y-axis shows the interruption duration in hours and the X-axis is the one-day duration. The minimum interruption duration is seen in case of joint micro-grid and main grid operation when compared with the micro-grid functioning alone.

Figure 6. Figure 6 is a bar diagram depicting customers average interruption frequency per day per customer interruption in two different conditions. The customer interruptions are shown on Y-axis over the one-day period which is taken along the X-axis. The lowest value is seen in case of joint micro-grid and main grid operation when compared with the micro-grid functioning alone.

Figure 7. This represents a bar diagram of the customers average interruption duration in hours per customer interruption in two different conditions (along Y-axis); X-axis is the one-day duration. The minimum interruption duration is seen in case of joint micro-grid and main grid in operation when compared with the micro-grid functioning alone.

Figure 8. The single important service reliability index is the average system availability index (ASAI) shown in Figure 8 along Y-axis whereas X-axis is one day period taken into account. By far the ASAI index is quite useful as the ratio of the total number of customer hours that service was available during a given time period (1 day) to the total customer hours demanded. This may be calculated on either a monthly basis (730 hours) or a yearly basis (8760 hours) but can be calculated for any time period (like 1 day in this case).

Conclusion. The paper focuses on the consistently growing concern of the electric utility companies to prioritize tight control on system performance owing to the health and environmental impacts associated with fossil fuels and use more and more solar energy as it immensely helps planning maintenance expenditure economically with customers expectations fully met. The measurement of system performance using a set of service reliability indices (Billinton and Allan, 1996) are already documented in IEEE Standard 1366 (October-2012) classifying SAIFI, SAIDI, CAIFI, CAIDI and ASAI. These reliability indices [6-9] based on outage frequency, outage duration, system availability, and other responses allow predicting interruptions that may occur in the power supply distribution network affecting adversely the safety of men and machines, and the level of production in the industrial sector. The sustenance of economic growth of a nation depends on its capacity building to supply electricity with reliability and security to industries enabling desired (or target) production and productivity of goods and services. The study reveals that the micro-grid powered by solar panel has **ASAI** (service reliability) equal to **0.99975** which is very competitive to the interconnected micro-grid and main grid ASAI (service reliability) equal to **0.99995**. Interestingly, the ASAI values in both the cases have been observed to be higher than $\mathbf{R_{SB} = 0.99967}$ (the critical value found under the most rigorous conditions imposed on the local area electric supply system). Moreover, in remote locations the micro-grid (stand alone system) has the numerous significant advantages in terms of economy, sustenance and ease in maintenance; and thus, is fast becoming a popular trend as an alternative to the national/regional grid power system.

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