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Grid Connected Photovoltaic System for Power Sharing Application Using MATLAB

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Abstract: This study presents, a single-phase five-level Photo-Voltaic (PV) inverter topology for grid-connected system. The equivalent model of PV panel is generating the electric power. The photo-voltaic arrays are connected to PWM inverter through the DC-DC boost converter. In this output of boost converter is constant. The inverter output is constant AC with suppl frequency, it is connected to grid. A digital proportional-integral-derivative current control algorithm is implemented in MATLAB version 7.5 to control the inverting operation. The PID current control scheme produces less harmonic distortion and improved sudden step response. The grid current is almost sine wave and the power factor is nearly unity.

Key words: SPV array, PWM inverter, PID current controller, MATLAB 7.5, India

INTRODUCTION

Global warming and increasing prizes of fossil fuels have drawn more attention towards the usage of renewable energy sources particularly solar energy because of its well known advantages. A great deal of research has been conducted in this field over the last few decades. Solar Photovoltaic Array (SPVA) panel is a power source having non-linear internal resistance. A major challenge in using a SPV source containing a number of cells in series is to deal with its non linear internal resistance. The problem gets all the more complex when the array receives non uniform insolation. Cells under shade absorb a large amount of electric power generated by cells receiving high insolation and convert it into heat. This heat may damage the low illuminated cells under certain conditions. To relieve the stress on shaded cells, bypass diodes are added across the modules. In such a case, multiple peaks in power-voltage characteristics are observed under non uniform illumination. In a solar photovoltaic array spread over vast area, it is likely that shadow may fall over some of its cells due to tree leaves falling over it, birds or bird litters on the array, shade of a neighboring construction, passing clouds, etc. Under partial shaded conditions the PV characteristics get more complex with multiple peaks. It is important to understand and predict them to get maximum possible power from the SPVA. In series connected array, even the slightest shadow falling on a PV panel causes a significant drop in generation power. The simulation of MPPT algorithm to track the global maximum is also presented. Overcome this problem to use DC-DC boost converter to maintain constant output. They generally perform the conversion by applying a DC voltage across an inductor which causes current to flow through it and store energy magnetically then switching this voltage off and causing the stored energy to be transferred to the voltage output in a controlled manner. The output voltage is regulated by adjusting the ratio of on/off time. The DC constant output is applied multilevel inverter, inverts DC-AC. The three common topologies for multilevel inverters are as follows:

- Diode clamped
- Capacitor clamped and
- Cascaded H-bridge inverter

In addition, several modulation and control strategies have been developed or adopted for multilevel inverters including the following: Multilevel sinusoidal (PWM), multilevel selective harmonic elimination and space-vector modulation. In this research presents, a five-level PWM inverter whose output voltage can be represented in the following five levels: Zero, $+1/2V_{dc}+V_{dc}-1/2V_{dc}$ and $-V_{dc}$. This inverter topology uses two reference signals such as V_{ref1} and V_{ref2} to generate PWM signals for the switches. Both the reference signals V_{ref1} and V_{ref2} are identical to each other, except for an offset value equivalent to the amplitude of the carrier signal $V_{carrier}$.

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Because, the inverter is used in a PV system is a Proportional-Integral-Derivative (PID) current control scheme. PID is employed to keep the output current sinusoidal and to have high dynamic performance under rapidly changing atmospheric conditions and to maintain the power factor nearly to unity. Simulation results are presented to validate the proposed inverter configuration. The inverter offer lower Total Harmonics Distortion (THD) improved step response and quality of power.

PHOTOVOLTAIC MODELS

Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted into electricity through photovoltaic effect (Selvaraj and Rahim, 2009). Being exposed to the sunlight, photons with energy greater then the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the influence of the internal electric field of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation (Vanitha and Sivakumar, 2010a). PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature. The PV panel is not available in MATLAB version 7.5, so researchers will go to equivalent model of PV cells (Tsai *et al*., 2008).

Thevenin's equivalent model: This theorem states that a circuit of voltage sources and resistors can be converted into a Thevenin equivalent current source. If a voltage V_{IN} is applied across a resistor R as shown in Fig. 1, a proportional current $I_{OUT} = V_{IN}/R$ begins flowing through the circuit according to the voltage-causes-current formulation of Thevenin's law ($I_{OUT} = V_{TH}/R_{TH}$). In this voltage-supplied circuit, the resistor R determines the current flowing through it thus converting the voltage V_{IN} into a proportional current I_{OUT} (Vanitha and Sivakumar, 2010b). In this way, the resistor R serves as a voltage-to-current converter-a linear circuit with transfer ratio $k = I_{OUT}/V_{IN}$ [mA/V] having dimension of conductivity (Hamrouni and Cherif, 2007):

$$\text{Current source} = \text{Voltage source} + \text{Voltage} - \text{to} - \text{current convert}$$

SPVA Model: The equivalent circuit model of a solar cell consists of a current generator and a diode plus series and parallel resistance as shown in Fig. 2. The mathematical equation expressing the output current of single cell is given by Eq. 1:

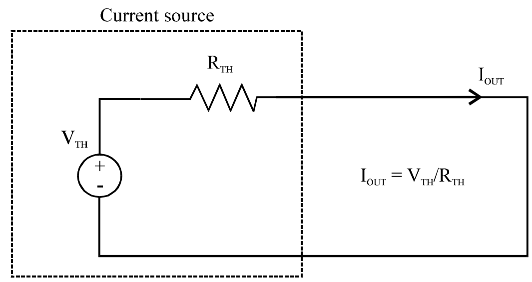

Fig. 1: Current source

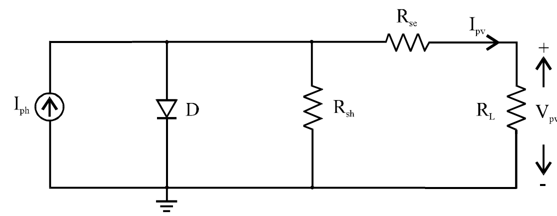

Fig. 2: Single photovoltaic cell

$$I_{pv} = I_{ph} - I_r\left(\exp\left\{\frac{V_{pv} + I_{pv}R_{se}}{V_t}\right\} - 1\right) - \frac{V_{pv} + I_{pv}R_{se}}{R_{sh}} \quad (1)$$

To get the improved model, the effect of insolation and temperature on each parameter has to be evaluated. For this, the following five reference parameters are required. They are V_{tref}, I_{rref}, I_{phref}, R_{seref} and R_{shref} are required. Under reference conditions Eq. 1 can be rewritten is given by Eq. 2:

$$I_{pv} = I_{phref} - I_{rref}\left(\exp\left\{\frac{V_{pv} + I_{pv}R_{seref}}{V_{tref}}\right\} - 1\right) - \frac{V_{pv} + I_{pv}R_{se}}{R_{sh}} \quad (2)$$

The mention earlier equations are used to simulate the model of existing solar panel which consists of 36 cells in series. Figure 3 shows that the series connection of SPVA with bypass diode. As with the connection of cells to form panels, a number of panels can be connected in series string to increase the voltage level in parallel to increase the current level or in a combination of the two (Rahim *et al*., 2009). The exact configuration depends on the current and voltage requirements of the load. Matching of the interconnected panels in respect of their outputs can maximize the efficiency of the array. The conventional PV panel is constructed of several PV cells

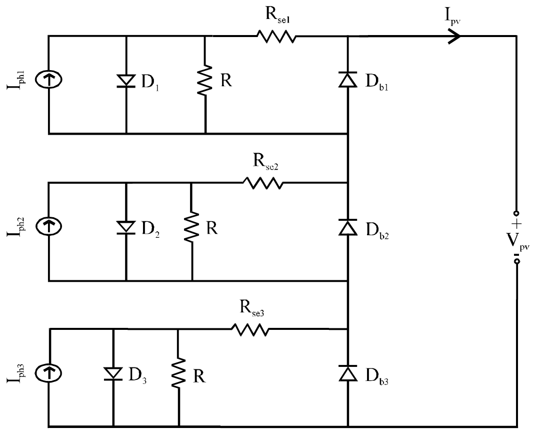

Fig. 3: Series connected PV array with bypass diodes

(normally 36 cells) connected in series. In the PV power generation system, multiple PV panels are generally connected in series in orderto obtain sufficient DC voltage (Rai, 1999). If there is one shaded panel in a series connected array, it can then act as a load to the array. It may cause damage to the panel due to the heavy current passing through it in the reverse direction. To prevent this damage, bypass diodes are connected in anti parallel with each panel and in case of the panel being shaded current flows through the bypass diode rather than through the panel. In series connected array, even the slightest shadow falling on a PV panel causes a significant drop in generation power. Overcome this problem to use DC-DC boost converter to maintain constant output.

DC-DC boost converter: The DC-DC boost converter (step-up converter) output voltage is always greater than input voltage (V_o>V_{in}) as show in Fig. 4. It's consist of inductor, diode and switch S_B. A switch is connected across inductor and supply (Rahim and Selvaraj, 2009). The diode D_1 blocks the reverse flow of output current when switch is turned ON. Whenever, the switch is turned ON, inductor current rises and stores the energy from supply. A switch is turned OFF; inductor current discharged and always improved output of the converter. The output voltage and current are continuous mode and ripple-free. The output voltage will be Eq. 3:

$$V_o = V_{IN} + L\frac{diL}{dt} \tag{3}$$

Thus, the output voltage is greater than supply voltage, this shows the step-up operation. It's

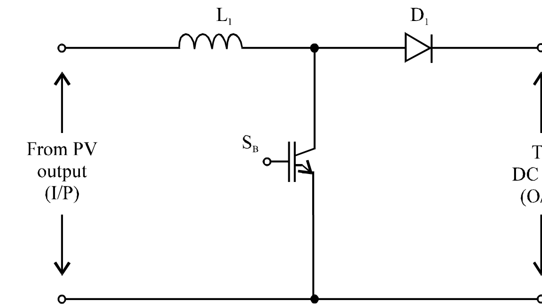

Fig. 4: DC-DC boost converter

maintaining constant output voltage. The constant voltage condition must be considered in grid-connected system (Araki, 2009).

The range of PV cells output is 80-115 V because of change in weather condition, it is likely that shadow may fall over some of its cells due to tree leaves falling over it, birds or bird litters on the array, shade of a neighboring construction, passing clouds, etc. The DC-DC boost converter, maximum power from PV cells and minimum power from PV cells of the ratio is step-upped to fixed output voltage. In this output voltage is apply to five-level inverter through the DC bus (Rahim *et al*., 2009).

PROPOSED INVERTER TOPOLOGY

The proposed inverter topology is consists of PV array. DC-DC boost converter, DC bus, five-level H-bridge inverter, utility grid as shown in Fig. 5. The PV array is generated DC power through solar energy. The DC-DC boost converter is used to track the maximum power of the solar arrays (Carrasco *et al*., 2006). The five-level inverter is used to conversion of DC-AC voltage. The AC voltage is connected to grid-system, i.e., utility feeder through filtering inductor. The injected current must be sinusoidal with low harmonic distortion. The load is considered as resistive and inductive load (Hassaine *et al*., 2007).

MODULATION TECHNIQUE AND OPERATION OF PROPOSED INVERTER

The main objective of designing a grid-connected PV inverter is to inject sinusoidal current into the utility grid. In order to generate sinusoidal current with low harmonic distortion, a sinusoidal PWM is used since it is one of the most effective methods. The proposed PWM modulation strategy is shown in Fig. 6. Two reference signals V_{ref1} and V_{ref2} and triangular carrier signal $V_{carrier}$ were used to generate the PWM switching signals. The modulation

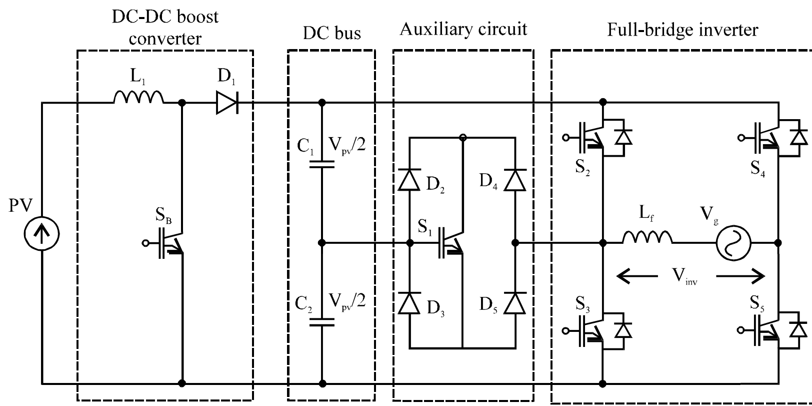

Fig. 5: Proposed inverter topology

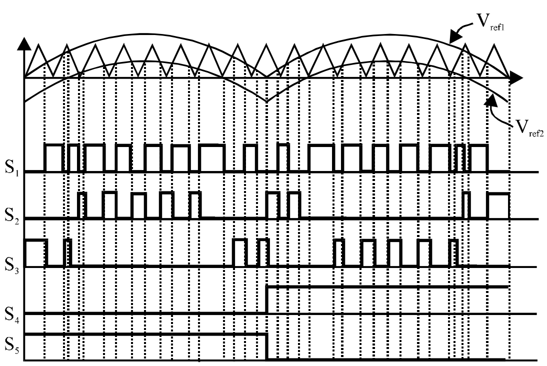

Fig. 6: Switching pattern for the single-phase five level inveretr

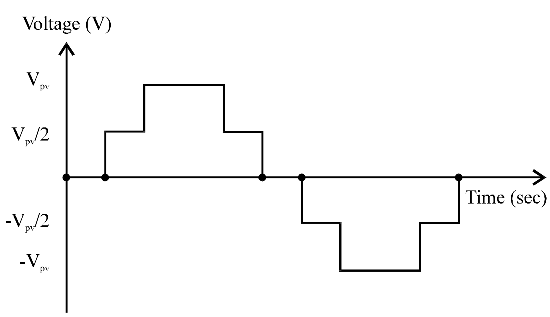

Fig. 7: Ideal five-level inverter output voltage

index Ma is maintained between 0-1. The output voltage produced by comparison of the two reference signals and the carrier signals can be expressed as Fourier series coefficient in Eq. 4:

$$V_o(\theta) = A_o + \sum_{n=1}^{\infty}\left(A_n \cos n\theta + B_n \sin n\theta\right) \quad (4)$$

n = even number, so $A_o = 0$, $B_n = 0$

Table 1: Inverter output voltage during S_1-S_5 switch ON and OFF

S_1	S_2	S_3	S_4	S_5	V_{inv}
ON	OFF	OFF	OFF	ON	$+V_{pv}/2$
OFF	ON	OFF	OFF	ON	$+V_{pv}$
OFF	OFF or ON	OFF or ON	ON or OFF	ON or OFF	0
ON	OFF	OFF	ON	OFF	$-V_{pv}/2$
OFF	OFF	ON	ON	OFF	$-V_{pv}/2$

$$V_o(\theta) = \sum_{n=1,3...}^{\infty}\left(A_n \cos n\theta\right) \quad (5)$$

$$A_n = \frac{4V_{pv}}{n\pi}\sum_{m-1}^{p}\left[(-1)^m \sin(n\alpha_m)\right] \quad (6)$$

Where:

m = A pulse number

α = The phase angle displacement

In this research, dual reference modulation technique is incorporated into the sinusoidal PWM technique to produce PWM switching signals for full-bridge inverter switches and auxiliary switch. The proposed inverter is to generate five-level output voltages, i.e., 0, $+V_{pv}/2$, $+V_{pv}$, $-V_{pv}/2$ and $-V_{pv}$. The auxiliary circuit consists of four diodes and switch S_1; it is used to generate half level of PV supply voltage, i.e., $+V_{pv}/2$, $-V_{pv}/2$. The five-level inverter output voltage V_{inv} is shown in Fig. 7. Table 1 illustrates the level of V_{inv} during S_1-S_5 switch ON and OFF.

CONTROL SYSTEM AND ALGORITHM

The proposed inverter is used in a grid-connected PV system. Therefore, a PID current control scheme is employed to keep the output current sinusoidal and to have high dynamic performance under rapidly changing atmospheric conditions and to maintain the power factor at near unity. As the irradiance level is inconsistent throughout the day, the amount of electric power generated by the solar modules is always changing with weather conditions. To overcome this problem, Maximum Power Point Tracking (MPPT) algorithm is used. It tracks the operating point of the IV curve to its maximum value through DC-DC boost converter. It's used maintain constant output power which is compare input and output of the converter. Therefore, the MPPT algorithm will ensure maximum power is delivered from the solar modules at any particular weather conditions. In this proposed inverter, Perturb and Observe (P&O) algorithm is used to extract maximum power from the PV modules. The feedback PID current control senses the current injected into the grid also known as grid current I_g and feed back to a comparator which compares it with reference current I_{ref}. I_{ref} is obtained by sensing the grid voltage and converting it to reference current and multiplying it with variable m. The instantaneous current error from the comparison between I_{ref} and I_g is fed to a PID controller. The resulting error signal u which forms the dual reference signals V_{ref1} and V_{ref2} is compared with a triangular carrier signal and intersections are sought to produce PWM signals for the inverter switches. This is to ensure I_g to be in phase with grid voltage V_g and always at near unity power factor. All the algorithms are developed in C^{++} language and it is implemented to MATLAB version 7.5.

Formulas: The PID algorithm of the continuous time domain can be expressed in Eq. 7:

$$u(t) = K_p e(t) + k_i \int_0^{\tau} e(t)d\tau + k_d \frac{d}{dt} e(t) \tag{7}$$

Where:

- u (t) = Control signal
- e (t) = Error signal
- t = Continuous-time-domain time variable
- τ = Calculus variable of integration
- K_p = Proportional-mode control gain
- K_i = Integral-mode control gain
- K_d = Derivative-mode control gain

SIMULATION

The simulation results are performed by using MATLAB 7.5. The maximum output of the PV array is 115 V. The minimum and maximum output voltage of PV cells is step-upped to fixed DC voltage as shown in Fig. 8a, b. The DC-DC boost converter is step

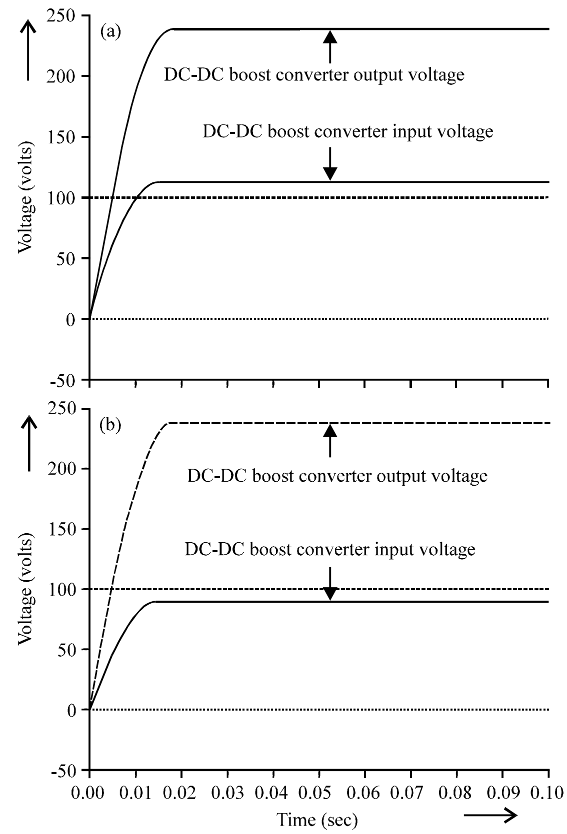

Fig. 8: The minimum and maximum output voltage of PV cells is step-upped to fixed DC voltage

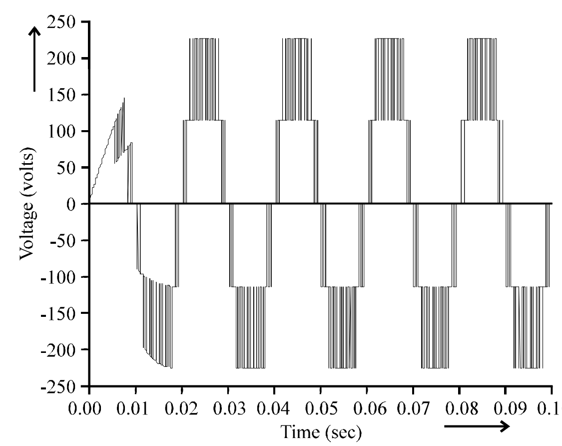

Fig. 9: Proposed inverter output voltage

upped constant output voltage 230 V and the five-level inverter inverts DC-AC voltage. The output of the inverter is 230 V, 50 HZ, respectively. The simulated result for the five-level output voltage and grid current is almost pure sine wave is given in Fig. 9 and 10. The grid current is variable and it is depends upon load. The PID current

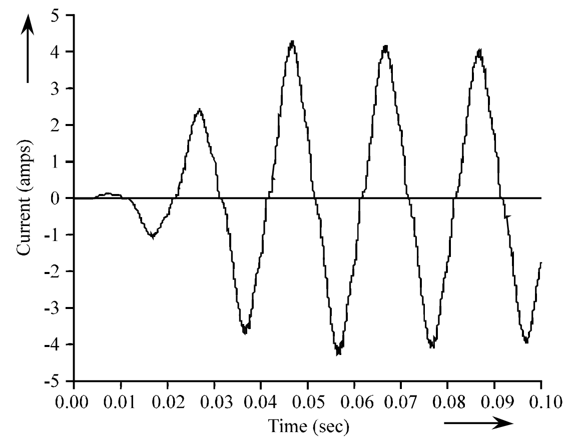

Fig. 10: Grid current

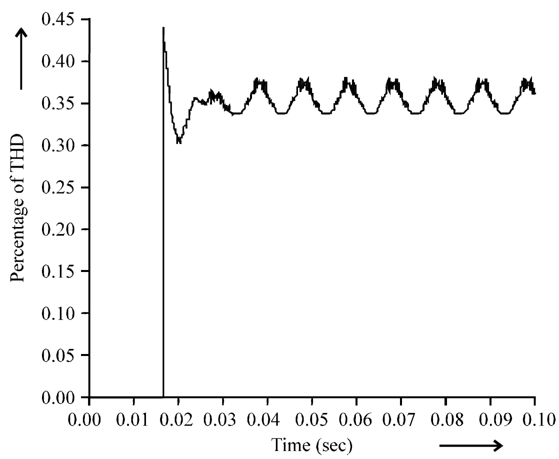

Fig. 11: THD in PID current control scheme

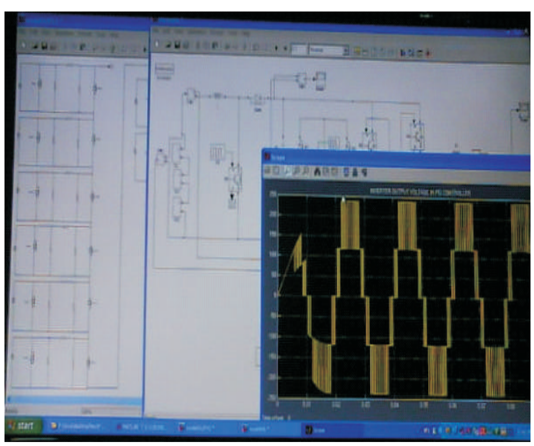

Fig. 12: Simulated view for proposed inverter

control scheme produces less harmonic distortion and improves the sudden step response is shown in Fig. 11. The total harmonic distortion should not excite in 0.45%. The power factor can be calculated mathematically and the obtained the power factor is nearly unity. The photo simulated view for proposed inverter is show in Fig. 12.

CONCLUSION

This study presented a single-phase five-level Photo-Voltaic (PV) inverter topology for grid-connected application. In this system should maintaining constant output voltage with supply frequency. The photovoltaic models, operation of proposed inverter topology, control system algorithm, modulation technique and simulation results were analyzed. The control system algorithms are developed in C^{++} language and implemented in MATLAB version 7.5. The PID current control scheme produces less harmonic distortion and improved sudden step response. The grid current is almost sine wave and the power factor is nearly unity.

RECOMMENDATIONS

The proposed inverter topology is single-phase, so researchers can use only in single-phase system. In this single-phase system is developed in three-phase system and also researchers can use real time application.

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